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ATOLL RESEARCH BULLETIN

Editorial Introduction

1. *Basic Information Papers*
2. *Symposium on Coral Atoll Research*

Issued by
THE PACIFIC SCIENCE BOARD
National Research Council
Washington, D. C., U. S. A.

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Editorial Introduction

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ACKNOWLEDGEMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board, including the launching of the Atoll Research Bulletin.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs, CIMA and SIM, during the past five years, of the second of which the Coral Atoll Program is a part.

The preparation and issuance of this Bulletin is assisted by funds from contract no. N7-onr-291-Task order IV.

Editorial Introduction

The Coral Atoll Research Program of the Pacific Science Board of the National Research Council has developed the need for a formal means of placing on record the data accumulated by the field teams for the use of widely scattered participants and prospective participants.

Eventually, of course, much of the more valuable information now available in a few copies will appear formally in various scientific journals, but it may be years before this happens. Meanwhile the information, even in a preliminary form, may be extremely useful in further stages of the program.

To make more widely available such preliminary information, as well as occasional summaries or reviews of certain aspects of atoll knowledge, the Atoll Research Bulletin is being inaugurated. It will consist of a numbered series of issues, to facilitate bibliographic reference. The numbers will appear at irregular intervals as papers are ready and funds become available.

These processed bulletins will be distributed to a list of institutions, selected on the basis of known, or probable, interest in this sort of problem, geographic location, and institutional stability. The selected list is appended below. In addition this bulletin will be sent to a small list of individuals concerned with program or known to be interested in some phase of research on coral atolls.

In any general ecological study, information from almost all branches of science may be required. Often satisfactory elucidation of ecological processes and clearness of understanding of ecological situations are in proportion to the breadth and fullness of knowledge of all aspects of these problems that are available.

The only limitation on subject matter acceptable for publication in the Atoll Research Bulletin is that it must have a definite bearing on coral atolls, but in general the information published will be that accumulated in the course of the Coral Atoll Program of the Pacific Science Board. Nevertheless, if suitable material from other sources is offered, and funds are available, it will be carefully considered. Decision as to what articles shall be published will be the responsibility of the editor and the advisory group.

Editing of contributions will be limited to minor grammatical corrections. If serious changes are needed, either in content or expression, a paper will simply be returned to the author for rewriting before acceptance.

Illustrations, maps larger than page size, or graphs or diagrams that are costly to reproduce will only be included if, in the opinion of the editor, they will effect a saving in text equivalent to the cost of reproduction, or if funds are secured by the author.

The Atoll Research Bulletin is not to be considered responsible for publication of all reports resulting from Coral Atoll Program activities or expeditions. Funds are necessarily limited and will be used for the papers which, in the opinion of the editor, are most essential to further development of the Program.

If an author is desirous of having a paper issued out of order, or for which funds are not available, and it meets the editorial standards of the Bulletin, it will be issued at once if the author can supply the necessary funds.

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ATOLL RESEARCH BULLETIN

No. 1

Basic information papers on coral atoll ecology

Published by

PACIFIC SCIENCE BOARD

National Research Council

Washington, D. C.

August 15, 1951

Contents of No. 1

These papers were prepared at the request of the Pacific Science Board as background information for use in two symposia on coral atoll research held in Washington, D. C., January 12, 1951, and Honolulu, T. H., February 5 and 6, 1951. The purpose of the symposia was to plan a program of scientific research pertaining to the general ecology of coral atolls.

Pacific Science Board
National Research Council
Washington 25, D. C.

Coral Atoll Symposia
12 January 1951, Washington
5 and 6 February 1951, Honolulu

INTRODUCTION

The Coral Atoll Project of the Pacific Science Board of the National Research Council is associated with Research Project E.6 (copy attached) of the South Pacific Commission which is concerned with Economic Development of Coral Islands. The phase of this project undertaken by the Board is largely in the field of basic research and involves essentially an ecological approach to the study of environmental factors effecting life on coral atolls. This involves three activities:

A. Field work conducted according to a uniform plan by teams of selected scientists on sample atolls in different climatic and cultural areas of the Pacific;

B. The assembling and correlation of known information particularly from literature on the Environment and Economics of Inhabitants of Coral Atolls; and

C. Program planning, advice, and evaluation of the results of research being conducted under A and B by an advisory committee of scientific specialists in fields represented in the Atoll Research Program.

During 1950 and early 1951, with Department of Navy assistance and the help of a grant of funds from the Office of Naval Research (under A), field studies on Arno Atoll in the Marshalls were conducted by thirteen specialists) in the fields of Anthropology (two), Geology (two), Geography (one), Marine Ecology (two), Botany (one), Vertebrate Ecology (one), Invertebrate Ecology (two), Soils and Crops (one), and Hydrology (one). Their team report and their final technical reports are now in preparation. Under B, a systematic combing of the extensive literature on coral atolls was begun in both Honolulu and Washington, and an annotated bibliography compiled. Under C, meetings of an ad hoc advisory group have been called in Washington (January 12), and in Honolulu (February 5 and 6).

The development of plans for the 1951-52 phase of the Coral Atoll Project will depend on the evaluation and recommendations of the ad hoc advisory group. It is hopefully anticipated that the Office of Naval Research will continue their support of this long range project involving basic research with applied aspects. Coral islands, wherever found, are of concern to the United States Navy.

H. J. Coolidge

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Ira LaRivers, Invertebrate Ecology, University of Nevada
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SOUTH PACIFIC COMMISSION

RESEARCH COUNCIL

Project No. E.6.

ECONOMIC DEVELOPMENT OF CORAL ISLANDS.

The general thinking on problems in the Area of the South Pacific Commission has been devoted largely to agriculture and improvement on volcanic and other large land-mass islands. The great per cent of the indigenous population is found on the large islands. But there is no place where the problems are so acute and their solution of greater concern to the peoples involved than on the coral or low islands. Moreover, the large islands, administered by diverse staffs, in which that for agriculture is always-prominent, are able to cope with their own problems to a great degree. The low islands are usually destitute of experimental resource, trained and experienced technical personnel. They may receive the benefit of sporadic investigation, but seldom of sustained studies based on and devoted to coral island production problems.

The economic circumstances on the coral islands are restricted. There are no pastures; there are no cattle. A few pigs and chickens constitute the livestock. Coconut palms cover most of the islands, with a few other tree species for local needs only. Often the population carrying capacity of the island or atoll has been reached. Copra has been the principal money crop. The atoll sun-dried copra, though small in total tonnage, is regarded as the best obtainable. Pandanus mats have been a second source of profit, but in this much depends on the local supply of fibre, skill and artistic imagination.

At this time there is no substitute for copra. The meagre, mineral-deficient soils do not support palms in full health and vigor. There is in sight no plant which offers itself as a substitute for the cocos, no product which can now replace copra for income. Coconut palms are replaced from time to time, and many are now at the end of their useful life. Replacements should be studied to the end that improvement in yield and vigor may be secured.

Food plants consist of breadfruit, pandanus, taros, bananas, some Polynesian chestnut, some citrus, arrow-root as a reserve generally, and scattered, individual plantings, as pineapples and sweet potatoes.

Pigs and poultry are kept in small numbers, the population of each being limited by the available feed.

The lagoon and reefs may supply fish and crustaceans. Pearl and trochus shells have a market, but it is not always profitable.

The low island people of the SPC area are the most deserving of assistance in the field of horticultural and economic security which the Research Council can promote. No programme of improvement will be rapid, because they cannot sacrifice present production for new or changing agriculture on a large scale.

Recommendations.

It is recommended that:-

1. A consistent program of coconut palm improvement be prepared, designed to:-

   (a) improve health and vigor;
   (b) increase yields; and
   (c) increase resistance to pests and diseases.

2. Food plant program be undertaken to study:-

   (a) the physiology of the breadfruit tree;
   (b) the preparation and extension of pits for growing wet land taro;
   (c) the introduction of bananas suitable to the area;
   (d) ways and means to increase the production of other food plants, especially those requiring additional fertiligy, as sweet potato, vegetables, citrus;
   (e) the supplementary nutrition of swine, ration of iron salts, and vaccination; and
   (f) improvement of poultry, both in egg laying capacity, time and weight development of birds, and freedom from diseases.

3. Information be gathered applicable to the extension of their commercial well-being, with attention to the increase in shell fisheries, either by planting of trochus and pearl shell, and the possibility of silk-grade sponges as a long time project.

4. Until such time as the economic situation on the low islands can be studied and their needs more particularly resolved, no large research allotment is requested.

5. In view of the urgent necessity to implement project E.5, the Administration of the Gilbert and Ellice Islands Colony be asked to proceed with the plan to establish a small agricultural station at ABEMAMA where there are facilities and where typical conditions are available.

6. In order that the work may proceed at an early date, an annual grant for 3 years of £ 500 be made toward the cost of wages, materials, maintenance and recording, on condition that the South Pacific Commission be kept informed of progress and results, and that the work is carried out to the satisfaction of the Commission.

7. That all administrations in whose regions atolls occur be asked for information in terms of recommendations (2) and (3).

8. That publication in Fiji Agricultural Journal of available information on these subjects be proceeded with for the guidance of resident officers.

9. That the Pacific Science Board of the National Research Council be invited to sponsor and finance an economic survey with special attention to the by-products of the islands. It is considered that this can be completed in 6 months.

Budget Note:

The Total provision recommended is £ 1500, of which £ 500 is required in 1950; £ 500 in 1951, £ 500 in 1952.

I. ECOLOGICAL RESEARCH ON CORAL ATOLLS

Coral atolls, scattered over a large part of the tropical seas of the world, provide a natural laboratory for research in tropical ecology that is unique and has scarcely been utilized. Although a certain amount of marine research has centered around atolls, their biota is so simple that it has not attracted much attention from students of land ecology. However, this very simplicity provides a situation almost ideal for studies of total environment and of human adaptations to and effects upon an environment.

Ecological research may take many forms. Essentially, ecology is a point of view from which almost any subject matter may be considered, that which emphasizes the interrelationships of living things and their environments. One of the most interesting types of such research is the study of a situation to determine what organisms inhabit it, what effects the various characteristics of the situation have upon them, what effects they have on the physical surroundings, and, finally, what effects they have upon each other. This applies not only to individuals of different kinds, but also to the members of one population of the same kind. The most severe competition of all is that between members of the same population. Further, it must not be overlooked that man is, of all the kinds of organisms in almost any situation, the one that exerts the strongest and most general influence.

Situations are usually selected for study because they are representative of a class of similar ones, so that the results of the research may be applied to the others of the class and may be compared with results of similar studies of other representatives to arrive at generalities. As in many other fields, the ecologist studying situations is able to adopt either of two very different approaches, that of studying one or a few examples very intensively, or that of studying many examples but much less thoroughly. Which of these approaches is best is a philosophical question that is not likely to be solved very soon. It seems unquestionable, however, that where both methods may be applied to one problem, the results will be more sound than those from either one or the other.

The complexities dealt with by ecology are probably greater than those facing any other science. Involved are, necessarily, a complete knowledge of the physical situation and the organisms in it, and their characteristics, requirements, and behavior. This is merely basic information. Then the innumerable processes taking place must be detected and understood. Finally, the effects of these processes on each other and on the various organisms must be determined, and an understanding of the resultant of all of these processes and effects arrived at, which should be an understanding of the situation itself. This ideal final product, this understanding of total environment, is the ultimate objective of ecological research.

Its value is so apparent that it scarcely needs to be pointed out. Such understanding furnishes the only real basis for complete control over a situation, the only basis for predicting the consequences of any use or alteration of any

factor in an environment, and the only possible basis for any rational sustained program for permanent habitation of any area by man or his dependent organisms. In other words, it is the only completely sound foundation for conservation and management of any segment of the total resources of the world we live in.

Most ecology gives the impression of being mired down in such a mass of complexity as to be getting nowhere, or of dwelling on single items out of context of the web of which they are a part. This is a logical result of the enormous complexity of almost all situations, and is likely to be extremely discouraging to one who has vision enough to see the whole picture.

The logical way out seems to be to begin with some of the simpler classes of situations. An understanding of some of these may well provide the methods and basis for approaching more complex ones. And, indeed, such an approach seems to have given the best results so far. The ecology of the far north, of deserts, of ponds and lakes, of certain grasslands, and of moorlands have made the most substantial progress.

Coral atolls provide another class of such simple situations, and one of the few possible ones in the tropics.

One of the reasons why a study of total environment is one of the most refractory and difficult of all lines of investigation is that it does not lend itself readily to an experimental approach, as the very process of experimentation will certainly modify the environment being studied. Ordinary experimental technique consists of keeping certain variables constant and manipulating others, in order to ascertain their effects. The nearest thing to a possibility of such an approach in studies of total environment is in a type of natural situation where certain factors are reasonably constant while others differ in various examples.

Coral atolls present nearly an ideal set of such situations. They are flat, eliminating all of the variables commonly associated with altitudinal differences. They are tropical and oceanic, eliminating significant temperature differences. They are calcareous, eliminating most significant substratum differences. They are structurally simple, minimizing hydrologic complexities. Their flora and fauna are small, reducing biological influences and making the biotic communities relatively simple. Thus a fairly understandable basic ecological pattern is discernible. Over this are laid variations in precipitation, size of island, distance from geographic sources of fauna and flora, period of human occupancy, cultural character of human occupancy, etc.

Understanding of the effects of these variable factors and of the functional dependencies between them and other factors may be approached by making comparative studies of several different atolls exemplifying differences in such variables as mentioned above. Comprehensive studies, such as those made on Arno by a team of workers, would be highly significant if available in addition for, say, a small dry atoll in the central Pacific, a small moist atoll in the central Pacific, a moderate sized moist atoll remote from large land areas, such as in the Tuamotus, an uninhabited moist atoll, possibly Maria in the Australs, and an atoll near large land areas, such as one in the Melanesian area, i.e., Sikiana.

If, over a period of several years, such a series of detailed, integrated investigations might be made, a fairly broad base of modern reliable comparative information would be established. Into this would be integrated the enormous amount of existing information being brought together by the bibliographic phase of the investigation. As a result it might be possible that a coherent and understandable picture of a limited tropical total environment would emerge, comparable to that developed for English mountains and moorlands by Pearsall (1949).

The significance of this in terms of human values is quite clear. There is no question that, in spite of the limitations of this atoll type of environment, human populations are going to live there, just as they have for many hundreds of years, at least. Atoll peoples had, left to themselves, evolved a mode of life very well fitted to this environment, and in a fair equilibrium with it. Though rigorous and simple, it was, so far as we may know, a happy and satisfactory existence. These peoples had come to terms with their environment and made the necessary adaptations for life in it.

During the past century and a half, expanding Western European Civilization has burst in upon these self-contained microcosms, inevitably shattering the equilibria established over the previous centuries. Disease, an altered religion, commerce, war, and confusion were the gifts of this alien culture. To some this change may be a matter of regret, to others merely a matter of intellectual interest, to still others it is moral elevation, while some call it "progress". At any evaluation, it must be accepted as a fact, and as irreversible. Modern transportation has become so effective that isolation, even for these remote atolls, no longer exists. The influence of western culture must now be reckoned with as a factor in any new equilibrium that is brought into being. Life for these people is thereby enormously complicated.

If modern science is to be of any real benefit to these peoples, as well as to others, it is probable that it must be in helping them to come to terms again with their environment, the new environment that has resulted from the shattering of the old. It is here that ecology, particularly the aspect of it dealing with understanding of total environment, is of vast importance. Understanding is certainly the first requisite toward dealing with anything. If this study of atolls contributes, over the years, to the readaptation of atoll peoples to their place in the world, as well as providing a key to the understanding of other, more complex total environments, it will have amply justified itself.

F. R. Fosberg

II. GEOLOGIC STUDIES OF CORAL ATOLLS

Coral atolls are organic communities isolated from influences of continental landmasses. The organisms that build the reefs are responsive to their physical and chemical environment, and, as they build the reefs and islands, these in turn influence the physical and chemical environment so as to provide a variety of ecologic habitats. Geologic studies of reefs, islands, and lagoons should provide the biologist with a pattern of zones of growth, erosion, and sedimentation, and should indicate the relations of these zones to environmental factors. The biologist's studies of the organisms in each zone should in turn help the geologist in interpreting the geologic history and paleo-ecology of the atoll from drill cores.

At present there are fairly well-integrated studies of the physical and chemical environment, the biology, and the geology, from very few atolls. Work at Bikini and the northern Marshalls has shown some relations of the pattern of reef zones and lagoon sedimentation to the prevailing conditions of surf, tides, and currents, and to changes in temperature and chemistry of waters on the reefs. It has been shown by drilling that the rocks at Bikini down to 2556 feet include a relatively complete section of limestone, mostly unconsolidated, through the Miocene and possibly including Upper Oligocene.

The relations of reef structures to the environment found at Bikini may not hold at other latitudes or in other island groups, and further work on a number of atolls at different latitudes both north and south of the equator is necessary.

Future geologic work should include:

1. Drilling. A deep hole to the basement rock should be drilled on an atoll that has been well studied. At Bikini such a hole would probably be 4000-7000 feet deep.

Holes to depths of 2500 feet, such as the one drilled at Bikini, should be drilled on atolls in every major island group. Lines of shallower holes to 300 feet or less should be drilled across islands and reefs on both windward and leeward sides of several selected atolls to relate the subsurface rocks to the topography of the lagoon and offshore slopes.

2. Oceanographic work. The physical environment of a number of atolls must be studied. These studies should include wave and current studies over reefs, lagoon circulation and exchange with the ocean, and accurate gauging of tides.

The chemistry of sea water, especially of that over reefs, is very little known. Oxygen, salinity, and pH measurements carried out over the diurnal cycle, and under different seasonal conditions, should be made on selected atolls.

3. Adequate facilities should be provided for lagoon studies. These facilities should include large ships with both shallow and deep recording fathometers, winches for dredging, and bottom sampling and coring apparatus. Smaller craft such as landing or rearming boats should be available for near-shore studies or for shallow water diving. A trained deep-sea diver could add greatly to our knowledge of lagoons in the zone of photosynthetic action.

4. Adequate aerial photographs, preferably overlapping photos on a scale not less than 1:5,000, should be obtained of as many atolls as possible.

The problem of the origin of islands on reefs might well be attacked by a survey of one of the islandless atolls, such as Ngulu Atoll in the western Carolines, or by a comparative study of Kayangel and the adjacent Ngaruangl atolls north of Palau.

Whether an island can form and become stabilized by vegetation under present conditions might be determined by finding out how large a sand and gravel accumulation, such as a bar or "temporary" island, must be before it can hold a freshwater lens sufficient to permit the growth of vegetation.

J. I. Tracey, Jr.

III. PACIFIC METEOROLOGIC PROBLEMS

The science of meteorology stands at a point where additional insight into the mechanisms and characteristics of the general circulation or hemispheric-flow patterns has become a problem of foremost interest. To have attained this point, it must be recognized that climatologic data and climatic research have been important stepping stones. It happens, however, that there are still great areas of the earth's surface for which inadequate, and in places, negligible climatologic data are available. In fact, there are areas where generalized upper air patterns are perhaps better known through the process of interpolation than detailed surface climatology. This is perhaps the case over broad ocean areas of the central and western Pacific.

Research in that part of the Pacific characterized by atoll development provides an opportunity for the collection of meteorologic data not only valuable to a knowledge of local biology and physical geography but also to broad problems of meteorology and climatology.

Intensive research in Pacific meteorology would demand resources far more widespread than those contemplated for any atoll research project. It is the purpose of this brief statement only to point out that date of regional as well as local significance can be obtained with the left hand, as it were, of any scientific project in the Pacific area. A very few of the possible problems are listed on which specific data might be readily obtained in connection with other work:

1) Estimates of the mean annual rainfall over the open ocean are, for large areas, very crude. Small islands of little relief offer opportunity for obtaining rainfall data which approximate the fall over the open sea.

2) Data on rainfall amounts in conjunction with indications of time of beginning and ending of rain, and concurrent observations of the time of day of specific shifts of wind direction, provide data for the analysis of the effect of the land mass on sea-land breezes. A problem of some interest is the minimum size of island required to cause sea-land breeze effects.

3) One of the important low-latitude meteorologic problems of the upper air is the nature and distribution of pressure waves in easterly wind currents. Though radiosonde data are required for detailed analysis, daily or twice daily observation of the direction of movement of clouds, particularly middle and high clouds, can be useful.

4) Temperature records are less significant meteorologically, from small island masses, than some other types of record. In oceanic areas, air temperature very near the beach can be compared with water surface temperature with profit. Temperature data requirements, however, should probably be dictated by biologic rather than meteorologic research needs.

Luna B. Leopold

IV. SOILS

Our present knowledge has two aspects: soil development *per se* (pedology) and the soil in relation to plant growth (edaphology).

SOIL DEVELOPMENT

Present state of knowledge: Most of information on atolls is from observations by biologists, geologists, etc. There are no analytical data of consequence in the literature. The Arno work characterizes only the wet atolls.

From studies on old raised coral islands the ultimate course of soil development on such materials is known. Present atoll soils are *regosols* and *lithosols*, representing relatively primitive stages in this development. Apart from catastrophe or uplife it is probable that these soils are foredoomed to self extinction as weathering reduces land height to sea level.

The probable short time course of soil development and effects of climate on it are inferred from observation, and from studies elsewhere, rather than known with any certainty. There are differences in existing soils attributable to moisture regimes, salinity, typhoon history, guano deposits, vegetation and man's activities but knowledge of their effects is sketchy and not well organized.

Suggested future research: Land formation, composition, age and weathering; permanency in relation to typhoons and solution. Soil development in relation to climate and time.

SOIL IN RELATION TO PLANTS

Present state of knowledge: As a first approximation, some of the probable effects on native vegetation and agricultural plants can be inferred from studies elsewhere. Ecological studies have stressed effects of soil and ground water salinity on vegetation but much more detailed information is needed. There are indications that soil nitrogen and phosphorus, and hence the cycle of these elements in vegetation, may be considerably affected by soil organisms (Baas Becking's notes) and sea birds. The Arno observations indicate soils are not as "impoverished" as often believed but some mineral deficiencies are known or suspected. The physical properties of soil can only be considered adequately in relation to moisture regimes and groundwater.

Suggested future research: Many investigations of this nature are probably best undertaken in connection with other projects; thus detailed observations should be made in connection with ecological studies, and agricultural improvement will require fertility investigations. Determination of the causes and distribution of the coconut maladies observed may require long term investigation. Evaluation of the soil resources of a given area will be needed for estimates of its potential productivity and carrying capacity.

Earl L. Stone, Jr.

V. FLORA AND VEGETATION OF CORAL ATOLLS

The flora of atolls is best discussed under several major headings. These are 1) Vascular plants, 2) Bryophyta, 3) Fungi, 4) Soil flora, 5) Marine algae.

1. The vascular flora of atolls is known in a general way, but as much from inference as from actual collections and observations. It is known that it is limited in numbers and that its most striking components are from the pantropic strand flora, with some admixture of more mesophytic elements in localities where conditions permit. Of the several hundred atolls and low islands known, we may say that the floras of Bikini, Rongelap, Rongerik, Eniwetok, Arno, Kapingamarangi, Satowan, Pingelap, the Hawaiian atolls, Rose, the Pacific Equatorial Islands, and Johnston Island are fairly thoroughly known. Those of most of the other Marshall Islands, Flint, Vostok, Caroline, Tubai, Maria, certain of the Tuamotus, Funafuti, Canton, Wake, Nomwin, Ant, Mokil, Ulithi, Woleai, Nukuoro, Cocos Keeling, Maldives, Laccadives, Chagos, and Alacran Reef, are more or less known, having been collected by more than casual visitors. The remainder, possibly the majority, are either not known at all or only very casually.

Recent intensive collecting on a few atolls has dispelled the idea that atoll floras are so uniform that they are not worth bothering with. Differences have emerged which suggest that if the floras of all of them were thoroughly known very significant patterns might well emerge. Certainly understanding might develop as to the effect of distance and habitat on the effectiveness of dispersal. The idea has also been suggested that if a large number of sea level atolls and those elevated ones known were thoroughly collected, statistical treatment of the results might yield evidence on the putative recent eustatic shift in sea level.

2. Only a few scattered bryophytes are known from atolls. On some of the dryer atolls there obviously are none. But very few collectors have been on any atoll long enough to bother about hunting for mosses. It may be safely stated that the bryophyte flora of atolls is essentially unknown.

3. The fungus flora is dealt with separately in a paper added by Dr. Rogers.

4. Notwithstanding its obvious importance, the microflora of the soil is scarcely known for any atoll. The work on the collections of Dr. Taylor from Bikini and neighboring atolls is the only exception. It has shown that there are at least notable floras of Chytridiales and Actinomycetales in atoll soils. Dr. Baas Becking's investigations on the blue green algae in the soil crust suggest that here is a field of great interest awaiting investigation.

5. The marine algae are also dealt with separately in the attached paper by Dr. Taylor.

The vegetation of atolls is even less well-known than their flora. Superficially the vegetation of most of them is rather similar, which has given rise to the notion that there are no significant variations in atoll vegetation. It is, however, obvious that there is a perfectly graded series from extremely dry and barren to very wet and lush atolls. Their surface features, land areas, and history of human occupation add other very striking variations. And it is very obvious that the role of hurricanes and typhoons in determining the vegetation is an important one.

Though superficial descriptions of atoll vegetation are many, careful, detailed ones are almost lacking. Millspaugh's paper on the vegetation of Alacran Reef, the descriptive parts of the Funafuti report, Rock's paper on Palmyra, Setchell on Rose Atoll, Christophersen's papers on the Central Pacific and Hawaiian atolls, descriptions of one or two atolls in the U. S. Commercial Company reports, and Taylor's recent book on Bikini are about all that are available. Taylor's book deserves further comment. Never before has such a thorough work on either the flora or the vegetation of an atoll been written. From now on it will be a basic point of orientation and comparison for all future studies.

Obviously, with such vast gaps in our information on both floras and vegetation of so many atolls, no opportunity should be neglected for further collecting and observation. Emphasis might well be laid on longer visits than the hit-and-run type so common in the past. This is especially necessary if significant descriptions of vegetation are to be prepared. Furthermore, no adequate picture of the cryptogamic flora, especially of the parasitic forms, the minute soil inhabiting plants, and the marine algae will be obtained without specific efforts being made toward these ends.

Another obvious task that should be undertaken is the preparation of a flora of coral atolls. This should be planned to include the plants recorded from atolls in the literature, records available in herbaria, and all new information that is accumulated during the course of the investigations carried on by this project, the Bikini project, etc. It could be carried in card-catalog form for several years, then brought together for publication. At least three people should be concerned with its preparation, one for vascular plants and bryophytes, one for fungi, and one for algae. These could obtain such collaboration as would be necessary from specialists of their acquaintance. The main centers of deposit of atoll plant specimens are the Bishop Museum, Honolulu, the U. S. National Herbarium, Kew, and the Paris Natural History Museum. These would have to be visited and combed for material.

F. R. Fosberg

V. (a) FUNGI

The fungi of the atolls have been little collected, and there are almost no published reports on them of any consequence. The German and Japanese students who gave occasional lists of fungi of the Pacific islands from the early 1800's into the 1940's seem to have devoted most of their attention to high islands. What fungi were reported from atolls seems to have been specimens picked up in passing by collectors seeking vascular plants, and they are all large fleshy or woody species. Except for the Marshall Islands, atoll fungi remain almost unknown. From that group only 16 fungi had been reported up to 1947. The recent book by Taylor, and the lists begun by Rogers, indicate that fungi are considerably more numerous in this group. Together these authors list 43 species; but since of their collections the Ascomycetes, the most abundant groups of Basidiomycetes, and the whole mass of foliicolous forms remain mostly unnamed, it is certain that in this best-studied archipelago the majority of fungi - at least three quarters of the species - remain unknown.

The gaps in present knowledge are such that no recommendation for an area of concentration is possible. Economic fungi - those causing disease of man and of higher plants, and those causing decay of timber and fabric - are almost completely unknown even from the Marshalls; distribution of species among atolls, and the relation of atoll to high-island fungi, are equally unknown.

D. P. Rogers

VI. ATOLL RESEARCH IN ZOOLOGY - LAND AND MARINE

The land species of atolls constitute a depauperate fauna of very few species dependent on the attainment of this isolated habitat after its formation as land, and upon the tolerance of such species for any habitats to be found upon atolls. The land species are mainly concerned with the forest ecology of leaf mold accumulation; such species as the minute land snails, for example. A second group is useful in the reduction or elimination of insects bothersome to man or to his efforts in agriculture. The small lizards belong to this group. The third group, some of which are scavengers of the atoll economy, may be, and are used in some cases for food by the atoll inhabitants. For example, the small rats may help support the cats, dogs, and swine of the natives. The large Coconut or Robber Crab, and birds and bird eggs are usually a direct source of food for the inhabitants.

The marine species of animals found in and around coral atolls are far less restricted than the land faunas, yet form a reduced fauna in comparison with that of continental or high-island habitats in the same geographic areas. The invertebrate animals particularly are of major importance in supporting the planktonic and benthic pyramids of food supply derived from the Ocean by the atoll inhabitants. Certain forms, such as the larger crustacea (Crabs & Spiny Lobsters), Mollusks (Clams & Oysters) are eaten directly. The many other species serve to help the growth of the vertebrate food supply that is the major direct food crop derived from the oceanic waters surrounding the atoll and filling the lagoons. Fish probably constitute the major portion of this crop on all atolls. Of secondary importance for food are the Sea Turtles, and the group of Porpoises; secondary because only captured occasionally. The birds, sometimes seasonally cropped from their rookeries, are usually Sea-birds, fed from the Ocean.

From a very hasty survey, one may say that most of our present knowledge of the Zoology of Coral Atolls is a widely scattered series of isolated faunal studies. That is, the great majority of this scanty knowledge is simply the determination of what species may be present in a particular closely circumscribed area. In the past there has been less time or inclination to study the ecology of species critically, except of course in the case of a few commercially valuable animal products, such as the Oceanic Pearl Shells.

Coral Reef and Atoll studies in Zoology include more or less complete faunal studies at: Tur (Red Sea); Mahebourg (Mauritius); Mascarene Ids; Maldive Ids; Laccadive Ids; Andaman Ids; Nicobar Ids; Cocos-Keeling and Christmas Ids; Port Galera (Philippines); Mariana Ids; Solomon Ids; Great Barrier Reef (Australia); Marshall Ids; Funafuti (Ellice Ids); Phoenix Ids; Fiji Ids; Rose Atoll (Samoan Ids); Tuamotu Ids, Rangiroa, Napuka, and Nganati; Marquesas Ids; Palmyra & Fanning Ids; and Pearl and Hermes Reef, Laysan, and other islands in the Hawaiian group.

Atoll Research in Zoology must include the study of animal species present, in relation to their relatives throughout the entire Indo-Pacific Region (and even in some groups the Atlantic also), before we can fully evaluate each species. It is only by study of the species on and away from atolls, that we may discover facts about each species concerned, to help in any program of development. This is true, whether it be a program of development of greater food supply for the inhabitants, or of improving the yield of such commercial products as Pearl Shell or the Watch & Instrument Oils derived from Porpoises and Dolphins. Ecological studies must be built on an absolutely biologically accurate foundation of species determination.

Joseph P. E. Morrison

VI. (a) - NOTES ON NEEDS FOR ENTOMOLOGICAL RESEARCH ON CORAL ATOLLS

Very little is known regarding the insect faunas of atolls. It is needless to stress our ignorance of the faunas, because it is all too obvious. But there are many more problems than the basic knowledge of just what species occur. We want to know their distributions. How do they fit into the plant-pollenating picture? What percentage of atoll plants are insect-pollenated? What part is played by phytophagous insects and the atoll plants? What about the parasites of birds? Bird diseases spread on atolls by insects? What about insect scavengers and animals? Practically nothing is known about the very interesting and peculiar marine flies which are more widespread in the Pacific than is generally realized. What are the seasonal fluctuations and how are they followed by insect population. Do the insects aestivate or hibernate? What about data on overseas dispersal - a very important point indeed. What conditions are most likely to bring in overseas stragglers? From what directions? What happens to fresh water forms when ponds dry up?

E. C. Zimmerman

VI. (b) BIRDS

Sea Birds:

The opportunity for work with sea birds is, of course, almost limitless. The principal breeding species of atolls are the Man-o'-War Birds, Tropic Birds, boobies and various burrowing or surface-nesting petrels. Not too much is known about the life history of any of these, particularly of the petrels. The ecological interrelations offer a broad field for study, partly in relation to the predatory habits of the Man-o'-War Birds. Even more important is a detailed quantitative study of any or all of these species. We know next to nothing about the seasonal succession of the petrels, for example, in relation to the rainy and dry seasons. We hardly know whether most of the resident species of sea birds breed continuously or have one or two nodes of maximum reproductive activity during the course of a calendar year.

The direction from the islands in which most birds go to feed is also extraordinarily important since this usually bears a direct relation to winds or currents, or both. The petrels and one species of the boobies seem to go much farther from the island than the other species in their regular, foraging, daily journeys. It has been suggested, but never proved, that the petrels are capable of carrying food in the throat and crop in an undigested state for a very long period, up to five or six hours. In the case of birds that feed as far as a hundred and twenty-five miles from a nesting station, this would seem to be a necessary physiological possibility, if the adult birds are going to be able to bring food back to their young, instead of having the process of digestion and assimilation go on within their own bodies during the return flight.

Very much needs to be learned about the migratory species from the northern hemisphere, particularly the shore birds, such as plovers, curlews, sandpipers, godwits, etc. With the exception of a few stations such as Hawaii, at the northern end of the winter range, and New Zealand, at the southern end, we know very little indeed about the movements of these birds and the climatic or other stimuli which mark the beginning of the return flight toward the north.

Still another opportunity is offered by the terns. Nobody knows yet where certain species go after the end of the nesting season. The Sooty Terns, for example, and, in some cases, the white Fairy Terns simply disappear into the immensity of the ocean. At least one Atlantic colony, the Sooty Terns have an interval of about nine months between their breeding periods so that the season of reproduction is constantly changing, or moving forward. Is this true of the same species in the Pacific? Nobody knows.

The eggs of many fish-eating species are perfectly palatable without any of the unpleasant flavor characteristic of the flesh of the same birds. It is possible, moreover, under proper management to take a regular harvest of eggs

from the breeding grounds of certain species, particularly the terns. This was done by the Polynesians over many, many successive generations without any reduction in the maximum numbers of the breeding birds, that is the largest numbers that the nesting areas are capable of supporting. White men, on the other hand, have seriously upset the balance and have even exterminated certain species at certain breeding stations. On the whole, perhaps, the worst of all dangers is offered by man's domestic animals, such as pigs, cats, dogs and, indirectly, of course goats and rats.

Robert Cushman Murphy

Land Birds:

Only very few species of land birds are found on coral atolls and even among these some are not strictly land birds, such as the Reef Heron, the Australian Gray Duck, and certain species of rails. The only real land birds found on some of the islands are fruit pigeons and warblers (Acrocephalus). As far as the fruit pigeons are concerned, we would like to know more about their seasonal movements, particularly from one island to the next and from one group of islands to the next. Are these movements large-scale and are they correlated with the seasonal appearance of certain fruits? What is the status of some of these species in view of the increased shooting on some of the islands? Is there any relation between time occurrence of rails and sea bird colonies?

Ernst Mayr

VI. (c) RATS

While I have not worked on atolls information available indicates that the Polynesian rat (Rattus exulans) is found on some. This rat is introduced by native methods of travel and able to maintain itself in habitats where little fresh water is available. It is not a destructive animal. On atolls where military supplies have been unloaded the destructive Mindanao rat (Rattus mindanensis) and even more destructive Norway rat (Rattus norvegicus) may have been introduced. The Norway rat cannot persist under usual conditions found on atolls but the Mindanao rat may. Since each of these three rats has different habitat requirements and different habits before control is attempted the species shou be determined. Control measures for each species on atolls could be worked out without difficulty. Measures to prevent the introduction of the two non-native rats should be investigated.

Robert K. Enders

VII. CORAL ATOLLS AND MAN

1. The limited potentialities of the environment make the coral atoll of special interest in the study of man in his environmental relationships. The narrow basis for human subsistence entails a certain simplification of the relationships between man and his habitat, and facilitates the analysis of these relationships.

2. In discussing the relationship between man and nature in the atoll environment, one must first clarify what it is that is being related. Previous papers have served to elucidate the distinctive features of the environment. "Man" - the term to which "environment" is being related - can be considered in several ways. We may first consider man shorn of his principal distinguishing characteristic - his culture. The relationship between the atoll environment and man in this sense is primarily in what manner and how well the resources of an atoll supply man's biological needs for survival. When man is considered as a culture-bearer, however, the relationship changes its emphasis and increases in complexity. Here we are concerned with a complex set of relationships between a distinctive environment and a set of traditionally patterned ways of behavior that control man's adaption to the environment and his adaption to his fellows. Traditionally patterned modes of behavior as an aspect of culture.

3. The atoll and man's biological requirements. In this connection, food is the most important factor. The kinds of food available on coral atolls is well enough known, but there is yet to be made an adequate nutrition study of native diet. Furthermore, food is produced through the use of a special set of techniques, by men organized in social groups, and is distributed and consumed according to traditionally sanctioned ways. The study of food production and native diet is most fruitfully examined, therefore, in its cultural ramifications. This brings us to the relationship between the atoll environment and man as a culture bearer.

4. The atoll environment and culture. The first question we may ask is whether the atoll environment is associated with a special culture type. Distinctive aspects of atoll cultures. Examples from Micronesia and Polynesia. The manner in which the atoll environment is related to culture should first be examined with respect to those aspects of culture most closely connected to the utilization of natural resources: technology and material culture; economic organization; social organization. Control of land resources and food production in the Marshalls as an example of the nature of culture-environment relationships. Resumé of present knowledge.

5. Recommendations for atoll research. Kinds of environment-culture relationships needing analysis in the field. Importance of a comparative approach. Type atolls. The factor of change as it affects environment-culture relationships, and the importance of studies through time. High islands and coral atolls. Relevance of atoll studies to problems of native administration. Summary and conclusion.

Alexander Spoehr

VII. (a) AGRICULTURE

Present state of knowledge: Atoll agriculture has two aspects, subsistence and export:

The outlines of the former and existing subsistence agriculture are clear. The native plants and their culture are reasonably well adapted and, supplemented by the sea, have been able to produce an adequate, although somewhat monotonous, diet. These plants, their culture and, in a general way, their desirability and extent of use are known. Knowledge of introduced plant performance is very meager although there are many empirical observations that could be brought together. Some of the obvious factors limiting plant growth are known but there are serious blind spots and there are few actual measures of productivity. A study of the nutritional adequacy of native foods is now under way.

The export agriculture is based entirely on copra and there is scant hope of diversification in the near future. There is little information available on means of increasing production and efficiency under atoll conditions although some such knowledge must have been accumulated by commerical plantations (e.g. Keeling-Cocos).

Suggested future research: Agricultural investigation should not remain the handmaiden of anthropology nor be content with empirical trials of this or that crop or practice. Rather it should aim at anticipating the needs, and providing the policy and leadership for the agricultural development of the area. To do so will require economic studies, crop and soil investigations and educational efforts.

Short term investigations alone are inadequate but can contribute; examples of these are an economic study of copra and the probable future competitive position of the atolls, and a survey of the crops and agricultural practices of the most well developed areas with similarities to the atoll environment. Longer term investigations are necessary for testing new crops, improved varieties and practices, and their utility and acceptance. Such investigations need not be on a large scale but they must be well conceived and carried through for some years.

Shaping of the native agriculture by education and demonstration is a task for extension. The synthesis of economic, biological and anthropological considerations to provide the basic facts and policy for such extension activities, however, is a research task of a high order. In this connection a long term, cooperative "pilot plant" test on a single area should be considered.

Earl L. Stone, Jr.

VIII. LITERATURE ON CORAL ATOLLS

In any serious research project an essential and unavoidable task is to become familiar with what is already known on the subject. The reasons for doing this are not merely to avoid pointless duplication of effort, but to establish a basis for comparison of results, to build a framework of established information into which to fit new findings, to avoid the errors and blind alleys of past work, and to give breadth enough to acquire understanding as well as accumulating information.

In the past it has usually been possible for any individual to depend on his own efforts in becoming acquainted with old literature and keeping abreast of current work. In recent years, however, the sheer volume of publication is such that in a field of any breadth a worker's full time could be spent doing nothing but studying the work of others. Various solutions to this problem are available.

Ignoring the work of others is so limiting that it need not be considered. Narrower and narrower specialization is the commonest path chosen, but the evil effects of this in limitation of understanding and complete loss of over-all significance of work are all too evident. Division of labor along another line is also being more and more resorted to with considerable success. This path lies in the preparation of annotated bibliographies, subject indices, and comprehensive reviews and digests of findings in broad or restricted fields by certain workers whose breadth of background and natural inclinations make them fitted for it. Though, since the days of Agassiz' dictum "Study Nature, not books", there has been a certain stigma attached to bibliographic work and a resentment about money spent for it, there is no question that the realities of the situation are forcing scientists to make more and more use of the work of the professional bibliographer. The success of such reivew journals as Botanical Review, Quarterly Review of Biology, and various industrial scientific journals, as well as the existence of a half-million dollar contract between the U. S. Navy and the Library of Congress to review the results of research sponsored by the Navy alone are ample evidence of the truth of this.

For several reasons the bibliographic work of the atoll project got off to a slow start. However, during the past four months a truly notable amount of work has been accomplished, largely due to the efforts of my capable assistant, Miss Sachet.

On logical, as well as practical grounds, the bibliographic work on atolls divides itself into four major segments. These may be concisely termed marine geology, marine ecology, land ecology, and anthropology. Our efforts, up to the present, have been concentrated on the third of these major divisions. It is felt that the monumental bibliography brought together by W. M. Davis in his volume on The Coral Reef Problem, in 1928, together with the unexcelled

bibliographic services of modern American geology, largely eliminate the need for any intensive work on marine geological bibliography. Marine ecology and anthropology are such extensive and important fields, in themselves, and with such enormous literatures, that the resources of the present bibliographic phase of the project would be dissipated without significant results if an effort were made to include them. Furthermore, it is felt that in fields of such great practical and popular interest it should not be very hard to secure funds for comprehensive bibliographic studies if the workers in these fields feel the necessity for them.

The field of land ecology has been construed as broadly as is necessary to cover the entire literature on atolls that is left after the other three segments have been removed. It includes the geography, the land geology, the climatology, the water supply, the soils, the vegetation, the fauna and flora, the economic plants, the agriculture, and the uses made of the natural resources by the people.

The bibliographic work on this divides itself naturally into two parts, the location and evaluation of the literature that exists, and the abstracting and organization of the part of this that seems significant and useful.

The first part results in an annotated bibliography of all the literature known on atolls, with annotations describing and evaluating the content of the papers sufficiently to enable the user to determine which papers he should consult for his own purposes. This includes a subject cross index to make it easily and efficiently used. This bibliography is nearly complete, though there will be many papers that will turn up that we have overlooked, especially in the field of systematic zoology. It is hoped that we have the most important ones. The total number of papers has turned out to be about twice as many as we estimated at the beginning. We hope to be able to find a publisher for this work to make it available generally. Meanwhile, a preliminary manuscript is being typed which will be deposited in the Pacific Science Board offices in Washington and Honolulu, and the files are being kept open for additions and for consultation, by the Pacific Vegetation Project.

For the second part we have set up a series of filing folders, classified in every way that we can think will be significant. Into these we are putting information abstracted from the papers that seem to be of enough interest to be worth abstracting. Copies or cross references are inserted for each item in every folder where it is pertinent. A copy of the abstracts is sent to the Honolulu office so that a duplicate file may be kept there. A visit was made to Yale University, where all material fitting into this scheme in the Cross Cultural Survey files was copied for insertion into this system. In addition, unpublished field notes are included wherever available. Though much information has already been inserted, an enormous amount remains to be done on this part of the project.

It is contemplated that, as time goes on, digests may be made and issued of the information accumulated on specific fields based on this abstracted data. It may be possible, after the greater part of the abstracting is done, to prepare

such digests to order to meet the needs of individual workers on the project. This would save much preliminary work for those engaged in the various aspects of the project, and might well save them from overlooking important information, and might direct their researches into important fields that could be overlooked otherwise.

It is felt that with another year of work, this bibliography and abstract file will be an extremely effective aid to atoll research. It also may serve as a model for similar work in the other major divisions of the atoll field.

F. R. Fosberg

ATOLL RESEARCH BULLETIN

No. 2

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ECONOMIC DEVELOPMENT OF CORAL ATOLLS

At the first meeting of the Research Council of the South Pacific Commission in May, 1949, the limited, precarious resources of the low islands native people of the S.P.C. Area were recognized, and a plan outlined for their economic improvement. In almost any instance the island population is running close to the limit which possible production has dictated. We are not here concerned with those few, temporarily successful islands where phosphates have given present security. It is the atoll of sharply limited production which we regard as the most deserving of assistance in agriculture, and in economic security.

It is the wish of normal people everywhere to be self sufficient. The atoll people are like that. It is only out of the surplus they can take from their subsistence needs that they acquire money and can participate in the goods the world has to offer. As a general rule their cash comes from copra, from mats or other fibre products, or from shell.

Economic development implies a train of improvements. There is first the greater production in island grown food; the coconut, the breadfruit, taros, sweet potatoes, vegetables and fruits; in swine and poultry. This means increased production per plant. There are no more acres to be added, no more rainfall to be secured, no more earth to be developed. The improvement lies in the biological sciences and the arts of agriculture. To do these things we must know much more about the conditions as they are, the potentials of plants and soils, of animals and feeds, and how to control waste.

The first plan was to study the economic situation in a representative atoll or group of atolls. The island of Tarawa (1°30'N., 173°00'E.) was selected in the Gilberts and Ellice Colony for this pilot project. For administrative reasons the work did not get under way in 1949. The second meeting of the Research Council in August 1950 reviewed the plans, confirmed the original intent, noted the interest of the South Pacific Conference which requested the Commission to give all possible priority to this project, and recommended a budget of £2,800 Sterling.

In December 1950 Dr. Rene Catala and Mme. Catala were employed by the Commission to undertake the economic survey of atolls in the Gilberts. A small agricultural station is proposed which will have a continuing status under the control of the Fiji Experiment Station. Dr. Catala is experienced in tropical agriculture, is an expert in marine ecology, and understands and is sympathetic to the life and necessities of the atoll people. He has obtained leave of absence from the Institut Francais d'Oceanie for this undertaking.

The time is short and the financial resources of the Commission are small. The survey is the beginning of what must be a long program of research and improvement. We are attempting to do for the atoll people in a short time what they cannot immediately do for themselves, but we must extend no false hopes, and make no promises we cannot abundantly keep.

H. G. MacMillan

GEOLOGY AND GROUND WATER OF ATOLLS

The geological problem of the origin of coral reefs and atolls has been one of recurrent interest and great durability, commencing with the famous subsidence theory of Darwin (1837). Both geologists and biologists in the century since Darwin's publication have accumulated facts according to their opportunities and contributed to the discussion. Several divergent theories have been developed including Semper's lagoon-solution theory, Daly's glacial-control theory, and the antecedent-platform theory invoked by Ladd and Hoffmeister, with the greater number of workers supporting either the subsidence or the glacial-control theory. In recent years it has become apparent that for the various observed conditions no single answer may be sufficient, and that the merits of the leading hypotheses vary according to the age of the atoll and its location.

Of necessity the earlier work was largely limited to individual deductions based on the sea-level plans of atolls, very incomplete knowledge of their submarine slopes, and deductions only as to their structure. Increase in the number and accuracy of soundings, both around atolls and over the seamounts that appear to be closely related, has come through improvement in sounding techniques, particularly with the development of the sonic method. There has been increasing emphasis on the ecology of the reef-forming organisms and the environmental aspects of the various processes of erosion and sedimentation. Drilling on Funa-futi, later on the Great Barrier Reef and Kita-Daito-Zima, and last on Bikini has contributed data on the local structure but has not resolved the problem. Various geophysical techniques have been the most recent to be applied, as particularly at Bikini.

Until recently comparatively little attention has been given to the details of structure in the sections of the atolls above and at small depth below sea level in their relation tothe ecology of the subaerial organisms including man.

Three chief lines of study need to be continued:

1. Deep drilling and other crustal sounding investigation by geophysical techniques and bottom coring, under both atolls and seamounts;

2. Geological mapping, both subaerial and submarine, combined with analysis and evaluation of processes;

3. Ecological studies on the islands, on the reefs, and in the lagoons and oceans.

The results of all three must be combined with contemporary tectonic and paleogeographic knowledge to promote understanding of coral reef origins.

Present knowledge of the ground-water hydrology of coral atolls is limited to a few scattered spot observations and a detailed but short-period series of measurements on one island. Apparently with sufficient rainfall, the larger islands of an atoll are capable of maintaining lenses of fresh ground water,

generally of the Ghyben-Herzberg type, though subsurface structure may in some cases introduce complexities in their functioning. Recent studies indicate an important control of vegetation and human ecology by ground-water composition.

Research considered desirable inthe ground-water hydrology of atolls may be outlined as follows:

1. Shallow subsurface exploration to determine in detail the rock types and structure and the shape and nature of the fresh-water lens on enough islands to indicate the expectable range of conditions;

2. Long-term observations on islands with a variety of climates to determine the reaction of the lenses in size, shape, and salinity to tidal and other sea-surface fluctuations and to short-term and seasonal changes in rainfall;

3. Long-tefm measurement of rainfall on enough islands to indicate the distribution of rainfall over the ocean, and compilation of available rainfall data;

4. Pumping tests to determine the safe yield of fresh ground water from atoll islands;

5. Checking and extension of the studies on the ecological controls made by ground water.

Doak C. Cox
Dan A. Davis
Chester K. Wentworth

MARINE ECOLOGY

For purposes of discussing and planning coral atoll research in marine biology the field may be divided into four categories, each highly significant when standing alone but inextricably associated with the others. These are (1) marine biology in relation to native welfare, (2) conservation of marine resources, (3) commercial exploitation of tropical Pacific marine resources, and (4) significant biological problems related to coral atolls.

The first, welfare of native populations, should hold the ranking position in planned investigations of coral atolls. High population densities, infertile soil for agricultural activities, absence of adequate natural resources, and lack of technical knowledge among indigent natives focus greater attention upon the renewable resources available in the marine environment. To this end information should be obtained on native uses of marine products as subsistence or food resources, as implement and decorative resources, and as export or income resources. With respect to subsistence or food resources the following major items must be considered: species used, catch statistics, analysis of marine food requirements per person, methods of collecting or fishing, means of prepatation and preservation of marine products, use of marine organisms for fertilizer or as food for domestic animals, poisonous species, conservation practices, comparison of inhabited and uninhabited islets in regard to the abundance of desirable species, etc. With respect to income resources a broad survey of the abundance of exportable items should be made and then followed up with an economic appraisal of costs of production, available markets, and transportation problems.

From the standpoint of conservation the marine environments are in a healthy condition generally. However, should certain commercial activities ensue, there would be definite need for studies basic to conservation. We need not dwell long upon this subject as pertinent items are considered under other headings.

Commercial exploitation of marine resources is inevitable, indeed, a rather good start in this regard was made by the Japanese prior to 1941. Many problems arise which should be tackled ahead of extensive commercial developments while time is available to legislate conservation measures, rather than to follow with ineffective remedial action in the wake of overexploitation. Studies on the relation of atolls and other mid-oceanic islands to concentrations of tuna and tuna-like fishes, on baitfish species and their abundance in the lagoons of all atolls, on the biology and population characteristics of baitfish, methods of catching baitfish, and possible native participation in a baitfish fishery, on poisonous commercial fishes, on the abundance and biology of trochus and other shells of commercial importance, on the abundance and biology of spiny lobsters, etc.

Coral atolls in particular and the tropical Pacific in general are considered to be the finest natural laboratories for a legion of fundamental biological and oceanographic problems. Important among these are (1) the effect of atolls on the surrounding oceanic environment, from the standpoint of vertical

water movements, concentration of nutrient salts, biotic effects of the dispersal of larval forms produced by inshore or lagoon organisms, and phyto- and zooplankton production, (2) systematics and accompanying zoogeographic interpretations of the Indo-Pacific faunal complex, (3) effects of steady climatic conditions on annual or seasonal rhythms, (4) biology of corals, (5) landward progression of marine species via ocean beaches, (6) ecológical aspects of coral reefs, (7) comparative studies on lagoon vs. oceanic plankton, etc.

The foregoing synopses provide a general idea of the nature of marine biological problems of importance to coral atoll research. Since time does not permit a full discussion of them all, those placed on the agenda are considered most timely and stand the best chance of success at the current time with present facilities. Stress should be placed on worthy problems for investigation, rather than on the detailed methods of accomplishing the task.

Agenda

Note: those marked with an asterisk can be accomplished by members of an atoll research team during summer periods.

Native welfare

*1. General inventory of useful species.
*2. Use of marine products for subsistence and income resources.
*3. Methods of collecting and fishing.

Commercial fishing

*1. Baitfish resources.
*2. Reef fish and shellfish resources.
3. Abundance of economically important pelagic fishes in the vicinity of atolls.

Biological problems

*1. Ecology of coral reefs.
*2. Systematics and zoogeography.
3. Animal rhythms in the tropics.
4. Effect of atolls on the oceanic environment.

R. W. Hiatt

LAND ECOLOGY OF CORAL ATOLLS

Ecology is rather an approach than a subject-matter. Factual information from almost all other sciences makes up the raw material utilized by the ecologist, and, in its highest expression, ecology is an integration of all of these subject-matters around the central idea of their interrelationships, with special emphasis on those involving living things.

A natural consequence of this diversity of subject-matter is a tendency for the vast accumulation of information to swamp and obscure the basic patterns of relationship, and to delay the emergence of principles. At the same time, without the enormous amount of information, the actual true patterns of relationship cannot be determined or verified, and the essential complexity of natural situations is not realized.

To lessen this dilemma, it may be useful, as ecological information and thought on a given area or situation develops, to construct, from time to time, tentative or theoretical patterns of relationships and processes embodying and expressing what appears to be likely from the information actually at hand. These patterns can form frameworks around which new data may be assembled as they accumulate, and which may be modified, torn down and reconstructed as the facts demand. They serve to keep the basic relationships in their proper place of importance as information piles up and the picture becomes more complex. One of the most outstanding examples of this was the formulation of Darwin's theory on the formation of coral atolls. This, though dealing largely with a geological subject-matter, was one of the outstanding ecological generalizations of all time. It has been assailed mightily, modified as new data were secured, but has provided a framework for the thinking in an important segment of both marine geology and marine ecology.

It is proposed here to outline briefly a tentative historical ecological approach to terrestrial problems on atolls. Arbitrarily, because it provides a satisfactory geological framework, simplifying the time relationships to where they do not obscure the problem, and because it provides an automatic solution for certain otherwise difficult biological problems before they can even be raised, one of the several alternative geological theories on the origin of land on atolls is adopted. This does not imply acceptance of this theory or loss of sight of its purely tentative nature, and if it were to be abandoned, the only aspect of the pattern here proposed for the land ecology that would have to be modified would be the time relations. Certain other problems, also, would then arise and need solution.

This geological framework postulated, during the post-glacial xerothermic period, an all-time maximum sea-level two or three meters higher than the present one. Postulated also, as a logical consequence, is a wide distribution, in tropical seas, of sea-level banks, living reefs, awash, with no permanent land, excepting possibly occasional isolated dry-land atolls resulting from local elevation.

It postulates, also, a subsequent world-wide lowering of sea-level to the present one, possibly coincident with the accumulation of the Greenland and Antarctic ice-caps.

This would have produced a large series of relatively uniform examples of a new habitat, the atoll islet, available for colonization by plants and animals and for primary vegetation development.

The outstanding characteristics of this habitat were as follows: physically it was flat exposed reef-rock, probably partially covered by rock debris, foramniferal sand, and shells of mollusks, Its drainage was practically perfect down to sea level, its relief very low or none at all. It had a high instability of substratum under influence of wind, storms, and waves, an extremely high insolation, and high surface temperatures. Chemically it was very saline, calcareous, basic, low in iron, high in magnesium and nitrogen, with a little organic matter but no humus. This makes up, on the whole, a highly inhospitable environment for most organisms.

Immediately upon emergence from the sea certain processes commenced which gradually altered this habitat, the alteration being more marked or more rapid in some examples than in others, depending on the climatic and geographic area in which they were situated. The more obvious of these processes may be itemized, with remarks on their effects:

1. Leaching out of the salinity by rainwater, but its continual renewal to some extent by spray and storm waves, as well as diffusion from below sea-level. The more this process proceeds the more species of plants are able to gain a foothold.

2. Piling up of clastic material on seaward sides of islets by storm waves.

3. Piling up of foramniferal sand and finely divided fragments of all kinds of organic calcium carbonate on the lagoon side, and their shifting by wind.

4. Establishment of individuals of the most extremely halophytic of strand plants from seeds cast up by waves or brought by seabirds - such species as Scaevola frutescens, Messerschmidia argentea, Ipomoea pes-caprae, Boerhavia diffusa, Triumfetta procumbens, etc.

5. Visits of sea birds, augmenting the phosphorus and nitrogen content of substratum.

a. Colonization by land-crustacea with planktonic larvae.

6. Gradual building up of a thin lens of fresh or brackish water in the substratum.

7. Weathering of rock by solution and by physical abrasion, resulting in some compaction of soil. Materials exuded from roots of plants, or released by their decomposition might augment this process, as might the actual physical penetration by the roots of porous fragments.

8. Accumulation of fine wind-blown material, caught by plants, resulting in the formation of small dunes and in the gradual assorting of the material from coarse fragments on the windward side to finer and finer sediments to the lee or usually the lagoon beach.

9. Formation of "beach-rock" by cementation of sediments under influence of fresh water, resulting in increased stabilization of substratum.

10. Development of simple plant communities by increase of first colonists and the addition of others with time, possibly several grasses, Fimbristylis, Pandanus tectorius, Suriana maritima, Tribulus cistoides, Wedelia biflora, Ipomoea tuba, and in wetter atolls, Pisonia grandis, Ochrosia parviflora, Barringtonia asiatica, Terminalia samoensis, etc. Most of these are current borne, but the grasses and sedge may be carried by wind and Pisonia certainly by sea birds. These would bring about increased stability of the substratum, which would, in turn, permit increased integration of the communities.

11. Occasional arrival and establishment of terrestrial animal colonists, also fungi, with consequent slow development of a soil biota, and terrestrial biotic communities.

12. Production, over long periods of time, of depressions in the centers of islets, possibly by solution and removal or redeposition in finer form of coarser calcareous material by rainwater and tidal and temperature fluctuations of freshwater lens. If the tidal fluctuation is slight and the material fairly compact, the depressions are muddy; if the fluctuation and water movement is greater, they will be clear and rock-lined.

13. Development and multiplication of the plant communities and their gradual integration into a vegetation. This involves the modification of the environment toward a more stable and more favorable type, also the arrival and establishment of additional species, particularly those whose existence is made possible by the operation of the various processes that help modify the environment, and environmental factors that are dependent on these processes. Some of these are the addition of humus, shade, accumulation of sand, accumulation of guano, stirring by land-crabs, decrease of salinity, protection from wind, formation of muddy depressions, etc. Community development would culminate, theoretically, in the establishment of a more or less mesophytic forest of Pisonia, Ochrosia, Ficus, Calophyllum, Guettarda, Pandanus, Hibiscus, with epiphytic and terrestrial herbs, ferns, mosses, and wood-destroying fungi.

14. Development, under influence of mesophytic forest and soil biota, of a brown forest soil.

15. Gradual development, under the influence of varying salinity, slight variations of surface and elevation, gradation of size of materials from seaward boulder-rampart inward, and distribution of wet depressions, of a pattern in the arrangement of the plant communities that, while subject to much local variation, as well as regional variation due to climate, is rather characteristic of atoll vegetation.

The development of a normally complex flora and fauna, and consequently, of a normally complex vegetation and mosaic of biotic communities, is drastically controlled by a series of limiting factors inherent in the atoll environment and situation. These may be enumerated, noting such of their effects as may not be obvious.

1. Barrier of sea water and distance from sources of suitable species. This would vary in intensity with location, but would certainly be at least somewhat of a retarding factor to every group of organisms except sea birds and land crustacea with planktonic larvae.

2. Proximity of sea, with consequent high average level of salinity. A great many organisms simply cannot tolerate, physiologically, this condition.

3. High temperature, preventing much humus accumulation except under saturated conditions. The soils take a long time to become fit for the growth of most plants.

4. Uniformity of topography, original substratum, and early biotic colonization, limiting the numbef of ecological niches available.

5. Iron deficiency, due to high pH and possible lack of iron in original material. Many plants cannot thrive without more available iron.

6. High average incidence of typhoons and hurricanes with attendant destruction of biotic communities and frequently destruction or severe alteration of the substratum itself.

7. Probable short length of geological life of any given land surface. This lessens or eliminates the gradual accumulation, with time, of suitable species by chance, and greatly lessens the chance of local endemic species developing.

8. Relative youth of this habitat as a whole. This, also, would preclude any complexity that is dependent on great lengths of time.

The next era in the history of atolls started with the arrival of man. He came needing food and space in which to live, as well as materials for his arts and manufactures. These had to be supplied by the environment. A certain amount of direct alteration of the environment was inevitable.

With him came rats, lizards, flies, coconuts, breadfruit, Morinda, Eugenia, taro and taro-like plants, and possibly Tacca, and, at least in some regions, pigs and dogs. The introduction of these dependents of man undoubtedly resulted in the rapid destruction of many colonists which were precariously near the limits of their tolerance of this environment, or which were the natural prey of the animals, as well as the possible increase of certain ones for which the conditions were improved by the changes.

There was a gradual destruction of the most mesophytic vegetation on the most fertile soil, and substitution for it of forest of coconut palms or of a coconut-breadfruit forest with a sparse understory of Pandanus, Morinda, etc. Taros were planted in the muddy depressions, and gradually these were enlarged and elaborated into excavations.

The sea bird populations were reduced by the rats, hogs, and dogs, and their breeding areas were restricted to certain islets. This resulted in a reduction of the flow of phosphates and nitrogen to the soils of most islets.

As populations increased, the taro excavations were enlarged and their muddy soil turned into a muck by throwing in coconut refuse and other organic materials to increase the humus content. Other plants are brought to the atolls from nearby high islands and cultivated in these swamps. They become, in many regions, a basic part of the food supply, though in drier atolls, this method of taro culture did not prove feasible.

The populations tended to increase and exert pressure on the environment, but there was much fluctuation because of wars, typhoons, and other disasters.

Many of the driest atolls could not support a human population and were never successfully colonized or were later abandoned.

The arrival of European man brought on another era. Human diseases and disease carrying insects were introduced, and the native populations decreased rapidly in most areas. More aggressive species of rats were introduced, resulting in further reduction of native biota. Insects that attacked coconuts arrived in some places.

There was a rapid increase in coconut plantations and destruction of the native forest on the less fertile soils. Both this forest and the native coconut plantation were replaced in many areas by more orderly and efficient commercial plantations. The practice of burning organic refuse was introduced in some places, resulting in a less fertile soil. The diet and requirements of the natives began to undergo a change, with substitution of foods that could be bought with the proceeds of the sale of copra for those produced by the people or caught in the sea. The same occurred to an even greater extent in articles manufactured for other uses than food.

The series of world wars accentuated these tendencies in some areas, retarded them in others, and on many islands converted large areas into barren, unproductive air-strips or bases.

Ecological relationships on atolls are now in the midst of changes whose direction and probable effects must be studied to be understood.

This generalized picture of atoll ecology, from a historical slant, suffers most seriously from underemphasis of the regional differences resulting from variation in amount and seasonal distribution of rainfall and from distance from large land masses which serve as a source of colonizing plant and animal species.

These differences may be epitomized by saying that in drier regions the development of communities cannot go on to the stage attained on the wetter atills, that the faunas and floras are much smaller, the vegetation sparser and more scrubby, human influence is usually less or negligible, sea birds are much more numerous; the farther an atoll is from large land masses the smaller will its fauna and flora be in comparison with otherwise similar atolls that are closer to such land areas.

Though the picture presented here may seem to some to represent adequate knowledge and understanding, it must not be forgotten that it is purely theoretical, based, to be sure, on observations on many atolls, but on no direct historical evidence. Research is needed on all points of it to confirm or alter the propositions made here. The most urgent needs seem to be more complete inventories of the biotas and descriptions of the vegetation of most of the atolls, and a few strategically placed detailed and thorough studies of all aspects of atolls of widely different types and geographic areas.

It must be reiterated that atoll ecology is dependent on data from all other fields of atoll research, and that deficiencies in the information on any other aspect will reflect themselves in less reliable understanding of the ecology.

F. R. Fosberg

MAN IN THE CULTURE-ENVIRONMENT RELATIONSHIP

Coral atoll research may be related to the problems of human existence in a practical sense or in a theoretical sense. The practical approach is concerned with short-term studies of specific island communities under stress conditions which, in the Pacific, may be due to (1) the need for rehabilitation in areas disrupted by the war, (2) the limitations of food and other resources where populations are increasing beyond the capacity of the local environment to support them, and (3) the changing cultural and environmental conditions as provoked by the encroachment of Western civilization. The theoretical approach may result in significant contributions to a more complete understanding of the interaction and interrelationships which exist between man, his culture, and his natural environment. Some general principles may be formulated about the processes and dynamics of human adjustment to environmental conditions.

Coral atolls are notoriously small in land area and poor in natural resources. A delicate balance between man and nature must exist inevitably in such marginal regions. In order to recommend changes in stress situations, it is essential to understand the factors which operate to produce imbalance, and the processes whereby harmonious adjustment between human populations and their environments can be achieved. In coral atolls, the environmental conditions are relatively simple and comprehensible, and because of their relative isolation lend themselves better to study and analysis of operative factors for adjustment. A series of coral atoll studies in different regions and with different populations could well provide the laboratory conditions desired by scientists for controlled studies of culture-environment interrelationships. Anthropologists have long denied the dictatorial role of natural environment in the shaping of cultures. There is need, however, for reexamination of basic similarities where they occur in cultural adjustments to a given environment. There is need also for cooperative scientific research inthe various disciplines to supplement the anthropogeographic investigations which in themselves cannot explain the human situation in its total environmental framework.

In specific situations, such as Arno Atoll and its Marshallese inhabitants, specific data were required in anticipation of administrative measures to be undertaken in the interests of the islanders' welfare. The 1950 Arno expedition resulted in a general, though still somewhat superficial, understanding of the major problems in cultural adjustment of Arnoese to their environment. With more time available in the future, local differences within the atoll can be studied more intensively, as can also the more exact relationships between Arnoese individuals and communities and the various components of their enviromment. Recommendations have been made for ameliorative measures in the case of the Arnoese, but there is need for further research at Arno to study the efficacy of such measures as may have been enacted, and the accuracy of the observations on the basis of which these measures were recommended. Other short-term studies are required of coral atoll situations in the Carolines, the Gilberts, and the Tuamotus, in order that more can be learned about the use and adaptation of local beliefs, attitudes, habits, and institutions for improving the welfare of island peoples in these surroundings. Suggested focal points for investigation by teams of scientists from various disciplines are:

the relation between population dynamics and the functioning of land tenure systems;

land use in relation to spatial factors and the presence of various types of island resources;

conservation of food resources in anticipation of seasonal shortages and famine periods;

regulation of population growth in relation to current technological utilization of resources; and

cultural changes as reflected in changes in the natural environment.

Proposed agenda:

1. Short-term, practical research:
   - Areas in need of attention due to stress conditions.
   - Manner of making recommendations of specific measures to ameliorate conditions of stress.
   - Follow-up on efficacy of measures enacted.

2. Long-term, theoretical research:
   - Standardization of field procedures and topics for investigation, for comparative purposes, in any series of coral atoll studies.
   - Representative atolls which might be studied.
   - Theoretical problems to be investigated within the framework of culture-environment relationships.

3. Cooperative research techniques and methods.

Leonard Mason

CORAL ATOLL BIBLIOGRAPHY

The following are topics proposed for discussion during the symposium:

1. Importance. (This has been covered fully in Dr. Fosberg's paper prepared for the symposium in Washington)

2. Scope of atoll bibliography.

a. Definition of "atolls." (It has been suggested that raised and sunken atolls be excluded; likewise atoll-like barrier reefs, such as Truk, and coral islands on the Great Barrier Reef and near continental masses. This leaves what W. M. Davis calls "sea-level atolls." Even these range from the isolated, low, sand or "pancake" islet, without lagoon, like Jarvis, Vostok, Baker, Kili, etc., to the lagoon surrounded by a reef without land. Further discussion on this is desired.)

b. Geographical location. All atolls are located between the "Tropics" and chiefly in the Pacific and Indian Oceans. Report will be given on the catalog of atolls which has been compiled by the writer.

c. Subjects to be included. Discussion of Dr. Fosberg's major categories.

(1) Marine geology. (Under this seems to be included all the voluminous literature on the formation of coral reefs and atolls and their foundations, which subjects are included, up to 1928, but without abstracts, in W. M. Davis' large book. Need here is to abstract those pertinent to this bibliography listed here and all which have appeared since.)

(2) Marine ecology. (Many papers in this large field have a place in this bibliography; the problem is to determine which, and to abstract and index these.)

(3) Land ecology. (Dr. Fosberg notes such subdivisions as geography, land geology, climatology, water supply, soils, fauna, flora - including economic plants, and uses made of natural resources by the people.)

(4) Anthropology. (This covers all phases of human culture, history, and administration. It approaches (2) and (3) in man's utilization of plant and animal life, both on land and in the sea.)

3. Progress on atoll bibliography prepared to date:

a. Report by Dr. Fosberg on work done by the Pacific Vegetation Project.

b. Report on bibliographic facilities available in Hawaii.

c. Bibliographic data on atolls known elsewhere.

4. Remaining to be done:

a. Continued search for and abstracting of pertinent abstracts.
b. Completion of an inclusive subject index.
c. Reproduction and distribution of product.
d. Provisions for supplements.

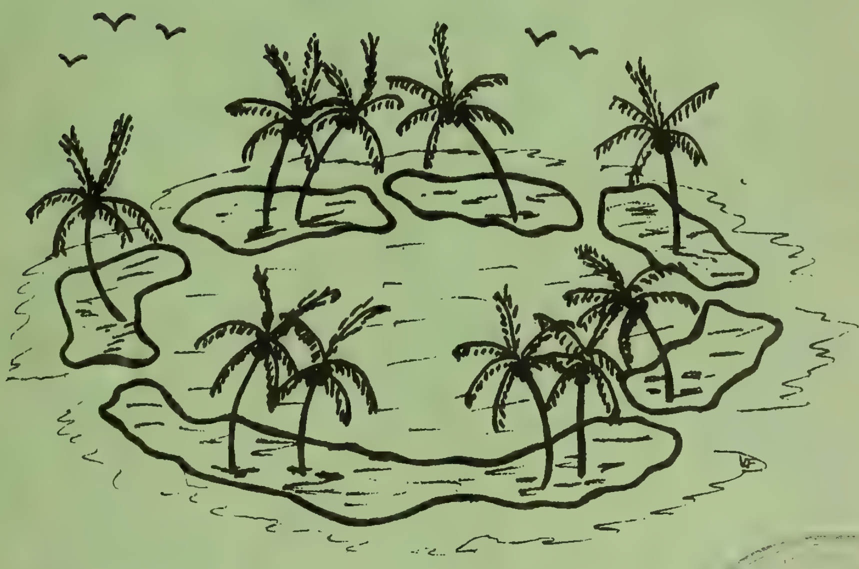
E. H. Bryan, Jr.

Nos. 3, 4 October 15, 1951

ATOLL RESEARCH BULLETIN

3. *Vertebrate Ecology of Arno Atoll, Marshall Islands*

4. *Marine Zoology Study of Arno Atoll, Marshall Islands*



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NOTICE OF CHANGE OF ADDRESS

Henceforth all communications
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It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board, including the launching of the Atoll Research Bulletin.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs, CIMA, SIM, and ICCP, during the past five years. The Coral Atoll Program is a part of SIM.

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VERTEBRATE ECOLOGY OF ARNO ATOLL, MARSHALL ISLANDS

SCIENTIFIC INVESTIGATIONS IN MICRONESIA

Pacific Science Board

National Research Council

Joe T. Marshall, Jr.
University of Arizona
Tucson, Arizona
November 1950

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The author wishes to take this opportunity to express thanks for the courtesies of the Naval Authorities at Kwajalein; for the help given by the CivAd Staff of Navy #3234 and in particular by Commander R. W. Kenney, Lt. V. L. Murtha, Mr. Blodget, Mr. John E. Tobin, Jr., and Mr. Ben Kesler, among others; and for the use of the laboratory facilities made available by the Doctors and Chief Pharmacist Mates of Navy #3234. Thanks are also due the civilians of Arno for innumerable contributions, of which just a few were the canoe trips by Mr. Clarence Overton, the identification of plants by Mr. Konto, and the building for a laboratory by Mr. Kotai.

The author is also indebted for the suggestions and helpful cooperation by other members of the scientific survey team at Arno; to Miss Ernestine Akers and Mr. Edwin H. Bryan, Jr. of Honolulu for their help; and to Mr. Harold J. Coolidge and Mrs. Lenore Smith of the Pacific Science Board office in Washington for their help.

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Objectives

It was my desire to record observations in the field on individual animals in their natural state. This information is preserved in my field notebook covering the period from early June to early September, during which time I was in residence at Arno. As few of the birds were nesting, and consequently very few were tied down to any restricted area, it was difficult to keep track of individuals. Most of the birds ranged over very large areas, but I did get continuous records on some for most or a large part of the summer: a certain Golden Plover (identified by his ragged primary feathers), a pair of reef herons, a nesting pair of pigeons, and a recognizeable flock of each of the following: crested tern, black-naped tern and turnstone. In addition, two brown Emoia lizards, which returned to certain roosts at night, and a school of porpoise were repeatedly observed in their appropriate places. For most of the species, however, I have considerable observations which disclose some interesting facts on distribution, aggregation into flocks, feeding methods, time of activity and movements, even though it was impossible to follow individuals.

Since the vertebrates (other than some of the lizards) found here are widely ranging over large areas in the Pacific and are well known, it was not thought necessary to do much collecting of specimens, aside from picking up an individual or two to look for parasites and stomach contents. I actually preserved 140 vertebrate specimens, most of them lizards.

My field observations make up the bulk of this report. The results of my collections of parasites and vertebrate specimens must wait (at least for some of the specific identifications) for determination by various experts on special groups.

Disposition of Specimens

Immediately upon landing in the U.S., I distributed specimens for identification as shown below. This is not necessarily a final disposition, and if you know of any institution that has a logical claim on any particular specimens, I would appreciate knowing it.

Concerning the lizards, I have corresponded with Dr. Myers of Stanford, the only person I know who might be working on Pacific reptiles in general, and he stated that he was not contemplating any particular project on Marshall Island reptiles; therefore, I have decided to work the lizards up myself, and publish the results separately. This study for one thing will involve trying to find names for the things, as you can tell from the strange vernaculars I have invented for them in the accounts which follow. I was amazed to learn from Dr. Myers' assistant that several of my Arno lizards were different from those which Myers obtained on Bikini! For this study it will be of help if I may borrow the specimens I donated to Dr. Wells of Cornell, and perhaps Dr. LaRivers will be so kind as to loan me the specimens he collected on Arno, provided he is not contemplating a major opus on them.

All mammal skins and skulls (2 species of rat, porpoise) and the only important bird skins (2 topotypes of a race of the Micronesian Pigeon found only in the Ratak Chain) to the <u>U. S. National Museum</u>.

Additional bird skins and skeletons: University of Arizona, Dept. of Zoology, Tucson.

Reptiles: Now at <u>University of Arizona</u> being worked up by myself; part of the collection is being sent to Cornell University and will be examined and identified.

Land snails taken from the intestine of the "Mennuel" lizard to Yoshio Kondo, <u>Bishop Museum, Honolulu</u>. This is the only item for which I have already received an identification. Mr. Kondo very promptly and kindly wrote (23 October):

> "The shell fragments you found in the skink's intestine are undoubtedly from several specimens of <u>Omphalotropis fragilis</u> Pease examples of which we recently acquired from Likiep, a nearby atoll. This is an operculate snail that lives under stones and debris throughout most of the Caroline Islands and it recently came as a surprise from the Marshalls and, I may add, as a jolt, out of a reptile. Snails are eaten by rats, birds, other snails, and perhaps by our mongoose but this latest is surely a new one on me."

I hasten to add that the lizards which have thrown the scientific world thus into such transports, were collected by Drs. Stone and LaRivers.

Intestinal protozoa and helminths of man, chicken, pig and native birds to Dr. Harold Kirby, Jr., <u>Department of Zoology, University of California, Berkeley</u>.

Intestinal protozoa of termites together with specimens of the termite hosts to Dr. Harold Kirby, Jr. When my flight out of San Francisco was delayed, I despaired of having enough time in Honolulu to gather equipment for preserving parasites. Dr. Kirby came to my rescue with his "complete termite kit" which made it possible for me to preserve slides and specimens of parasites of man and other animals as well as of termites. He is furthering our project by having his assistants stain and identify our human protozoa slides, etc., and it is only fitting that he should be given his beloved termite material - in fact that was his stipulation in lending me the kit.

Intestinal flagellates of lizards to Brontislaw M. Honigberg, <u>Department</u>

of Zoology, University of Massachusetts. A student of Dr. Kirby, Honigberg is writing his doctoral thesis on the flagellate faunules of reptiles' rectums.

Ectoparasites of wild birds and mammals (at the suggestion of Dr. Usinger) to Communicable Disease Center, U. S. Public Health Service, 605 Volunteer Bldg., Atlanta, Georgia.

Accounts of Species

Marine Turtle, Wön.- Seen only three times, in the lagoon.

1/ Rock Gecko, Kirabro.- This nocturnal lizard lacks the frilled adhesive discs found on the toes of the other geckos, consequently it is our only gecko that stays on the ground. It lives among rocks, and individuals are found on successive nights at their respective boulders. They are agile and can leap, but usually prowl slowly among the rock crevices. By day they may be found under stumps and logs or under piles of coconut husks. Two taken at 10 a.m. under a pile of husks had fresh food in their mouths, showing that they feed in the daytime in their dark retreats. Stomachs disclosed: their own skin, large centipedes, weavil, large spider, sand fleas, beach crickets, other small insects, some plant material. (In this and following stomach analyses, the insects have been identified by Dr. LaRivers.) Parasites: usually a couple of dozen nematodes attached in lining of stomach, rectal flagellates abundant. 6 specimens.

2/ Small House Gecko, Korab.- This small species is found abundantly in houses, and less commonly in Pandanus and Pipturus trees where it forages by climbing along slender twigs and hopping from leaf to leaf. In houses

1/ Rock Gecko (Gymnodactylus pelagicus).
2/ Small House Gecko (Lepidodactylus lugubris).

they begin hunting in late afternoon, and can climb vertical window panes. They are nocturnal, but are active for a longer period than the other geckos, being seen in late afternoon and early morning. By day they hide in the dead leaves of Pandanus, crevices in houses, under piles of coconuts, and under fronds and pieces of drift-wood on the beach. They do some feeding in these places during the day; two out of five collected at 11 a.m. under fronds and sticks on the beach, had fresh food. They can change color, and are usually dark in the daytime and very pale at night, but can change to agree with the substrate. Their call is a sharp "click, click" like two small pebbles striking together; a mating display was witnessed, involving jerky progression and sinuous waving of the tail. Food consists of small insects: ants, termites, Drosophila, sand fleas, and winged ants. A singular lack of habitat restriction is evidenced by the finding of individuals roosting by day in such places as houses, beach below the high tide mark, crown of a coconut tree, etc. The only parasites found were the rectal flagellates; 8 specimens were preserved.

1/ Big Tree Gecko, Korab Kiro.- This is the largest and most abundant gecko found on Arno; it is active during the hours of darkness. It is easily detected at night by its large red eyeshine (reflected from a flashlight) and one or two can be seen on just about every coconut palm, crawling along the midribs in search of insect food. They also climb along the slender palm leaflets, which their weight causes to bend down, and they cannot be shaken off by hand or by a strong wind, for the frilled pads on their toes virtually glue them in place. The tiny hairs on these pads

1/ Big Tree Gecko (Gehyra oceanica).

are apparently not easily wetted, for contrary to Loveridge's expectations (Reptiles of the Pacific World) I found these and the Small House Geckos in numbers climbing up wet surfaces immediately following a violent downpour of rain. These geckos are also found in thatched houses, Pandanus trees, but can most regularly be seen on tall dead coconut trunks, where there are crevices under the bark for hiding. They appear to avoid dense groves of breadfruit trees, and I saw only one individual in the King's breadfruit grove all summer. Of the hundreds of individuals seen, not one was on or near the ground. One afternoon I found four adults hiding in a "skirt" of hanging dead leaves surrounding a Pandanus stem. I found none by day in my "hectare" transect area; they probably roost high in the coconut crowns. Call notes and mating were observed in a house roof on July 7. The call is a loud, petulant "kraaaaaaa." Mr. Strasburg found a community nest: 14 eggs were in a hollow under some rocks at the base of a coconut stump. Any one female has only two ripe eggs at any one time. Stomach contents revealed their own skin, crickets, ants, crane flies, other insects. Fifteen specimens of all ages were preserved. These yielded in addition to the usual rectal flagellates, some interesting parasites: a stomach nematode, and rather large tapeworms in the small intestine.

1/Four-fingered Gecko, Korab.- This rare species closely resembles the Big Tree Gecko, but has a tail like that of the Small House Gecko, and the first digit is reduced in size. I saw only two on trees at night, and a third was brought to me by the village boys. Two specimens, rectal flagellates present, food of moths.

1/ Four-fingered Gecko (Hemiphyllodactylus typus).

Mennuel or "terrible lizard".- This giant skink was appropriately discovered by Dr. Stone some time after he had learned of it through Konto, who translated the Arnoese name of a certain plant as "sleeping place of the terrible lizard." Stone found two, and Dr. LaRivers one at Arno Island, on the ground, in the daytime. This gentle but formidable appearing animal is greatly dreaded by the Arnoese, but is certainly harmless. The three male specimens had no parasites; remains of land snails, Omphalotropis fragilis were found in their intestines.

Dasia smaragdina, Kilij (green form), Aoeb (black form).- This strictly arboreal skink is the diurnal counterpart of the Big Tree Gecko, and one or two can be seen on almost every coconut trunk during their hours of activity from about 7:30 a.m. to 5 p.m. (if sunny). They may remain motionless for long periods, pressed against the clear trunk, with the head held out at an angle. On uninhabited islands where there is denser vegetation, they will come lower in the leafy understory of vines and shrubs, but are rarely found on the ground. They occur on just about all the islets of the atoll; though I found none on Autore, one was seen on tiny Rakijer, much smaller than Autore, and containing only 3 or 4 coconut palms. A little islet next to Rakijer, which had only a growth of Scaevola, lacked any lizards of any kind. Dasia sleeps at night on the trunk, wherever they happen to be at the end of the day, as evidenced by the fact that individuals will seldom be roosting at the same spot on successive nights.

Their usual coloration is bright green, but some individuals are olive, yellow-green, brownish, black, or dark with yellow edgings to the scales, a very beautiful pattern. At Ine, I could expect to see only

two blacks out of fifty, but on islands at the east end of the atoll, such as Tagelib, Kirage, Ijoen, Rakaaru, etc., one usually saw a black one in every four or five.

Dr. Stone brought in an average sized Geograpsus crinipes (land crab) from the mouth of its hole at the base of a breadfruit tree, which he had caught in the act of dismembering and devouring an adult Dasia of fairly large size. Seventeen stomachs showed a diet of various insects: beetles, winged and non-winged ants, maggots, sow bugs, cockroaches, moths, etc.; two had plant material, one of them probably the white fruit of Scaevola. Eighteen specimens were saved, the rectal flagellates were in abundance, and the tiny nematodes often found in stomachs were probably escapees from the insect food.

Emoia cyanura, Kiruble (or Kirible).- This little blue-tailed skink is the most numerous land vertebrate on the atoll. It was abundant on all islands visited except one tiny islet of Scaevola only a few yards wide. It is found on or near the ground on piles of coconuts, fallen fronds, vines, gravel areas near the beach, lower matted dead leaves of Pandanus and thatched houses. There will be five or six on every pile of coconut husks, and they are so numerous in sunny vine areas, that there is a constant rustling as they jump from leaf to leaf; about one every square yard here! They rarely go up trees other than Pandanus, and I have seen them fall off when they attempt to scale smooth overhanging trunks. They are remarkably agile, and have a jerky, fast progression. They eat insects and some fruit (Scaevola), and in turn are eaten by herons, chickens, and possibly by the land crab, Ciserna. I once watched this crab pursue a

skink along a _Pandanus_ leaf, and the skink hid by pressing itself into the groove running along the middle of the leaf, such that it was almost impossible to see. They are active from 7:30 to five, preferring the sunlight. They are not found roosting in the open as are the other skinks, for they seek hiding places under rocks at night. 29 specimens were kept; as usual, flagellates were found abundantly inhabiting their large intestine and cloaca.

Ground _Emoia_, Karable (brown form), Aoeb (black form).- For the present, I am considering these two forms as being races or variants of the same species, because never were both to be found on the same island, and furthermore, the few young individuals that I was able to find of the black _Emoia_ had some brown coloration suggestive of the pattern of the brown form. It will be noted from the Arnoese vernaculars that the Arno people do not make a distinction between the black phase of _Dasia_, which is always found in trees, and the black _Emoia_, found almost exclusively on the ground. (On the other hand, these people recognise that all three radically different color phases of the Reef Heron belong to the same species.) Young individuals of the brown _Emoia_ are colored like the adults.

The distribution of the two forms is shown on the accompanying map. (Figure 1)
The species is absent on small islets such as Nameji and "Island No. 7"; Autore is the smallest island on which I found this skink. It is met with on the ground, rocks, piles of coconuts, base of breadfruit trees, gravel beaches under _Scaevola_ trees, and in houses, but it avoids dense vines and shrubbery. Those found on the bases of breadfruit trees commonly

run up and around the buttresses of these trees a few feet above the ground, but only once did I see one on a coconut trunk. This was an individual which I collected on Ijoen; it was affecting the manner of Dasia by clinging to the trunk 10 feet above ground, and holding its head out perpendicular to the axis of its body. It could be distinguished from the black Dasias in similar poses nearby by its shorter head, held out at a more rakish angle. This species is less abundant than E. cyanura (appropriate to its size): a coconut pile or base of a breadfruit which harbors half a dozen of the latter, will have only two of the former. One or two can be found at the base of almost every breadfruit, when there is a clear space there uncluttered by vines.

These skinks forage by deliberate movements, showing a strong tendency to crawl and poke their heads under things, such as under rocks, under mats on the floor. They crawl through the thatched roof to sun themselves on the top. They are tame and may climb over a person during their pursuit of insects. Food consists of earthworms, ants, maggots, other insects, and occasionally rotten breadfruit. One was eaten by a New Zealand Cuckoo which I collected. It is strange for a ground inhabiting lizard that likes to go under things that it should seek a higher perch in the open for roosting at night. I kept two such roosts under observation for about a month and found that one individual which roosted on a coconut leaflet four feet above ground was there three out of six nights, and another on a Pipturus leaf at the same height, was there eight nights out of eleven. They would occupy these roosts from about 6:15 p.m. until 7 a.m., and during the darkness would be fast asleep with eyes shut. They begin their activity in the morning when the sun shines on the

bases of the breadfruits, at about 7 to 7:30 a.m. 27 specimens were preserved, showing in the way of parasites, in addition to the prevalent rectal flagellates, stomach nematodes and a nematode encysted in the mesentery.

The strange mutually exclusive distribution of the two forms of this _Emoia_ is the most startling fact brought out by my modest researches on Arno. In continental areas two races of the same species will usually have each its own continuous area of distribution, and where the two areas adjoin, intermediate specimens will be found. But here, the two forms are interspersed in what seems like a haphazard manner, and continuity is evidenced only within the population of any one islet, where the individuals are all very nearly the same. The closest I found the two to each other was between Autore and the south end of Chittakinmatoroen, a distance of about a third of a mile. The black _Emoia_ was on Chittak, and the population of Autore was brown. It would be of immense interest from the standpoint of evolutionary studies, to interbreed the two in captivity and determine the genetic picture of their differences. Also it would be of interest, if anyone could spend a longer period of time in study at Arno, to release both forms on an island which has neither (such as Nameji), and see if one would survive at the expense of the other. It is very easy to catch these skinks with a simple noose, and a whole batch of them could easily be caught and brought together with most edifying results by one fortunate enough to spend considerable time on the project. If one assumes that both forms have equal opportunity to be transported (say in _Pandanus_ roof thatching which the faithful bring from all parts of the atoll for adorning the church at Ine) from island to island, then why do we find only one or the other (not both, not a mixture) surviving on any island?

Demigretta sacra, Reef Heron, Kabaj.- This heron is a permanent resident found on reefs throughout the atoll in numbers of about four to the mile. I found no direct evidence of nesting during the summer, although a specimen taken July 17, had a greatly enlarged oviduct and two ruptured ovarian follicles, and Dr. Wells observed copulation in a pair that I had under observation all summer at Ine Anchorage. I never witnessed this act nor did I find a nest, though I saw these two engage several times in rather elaborate mating display, and one would generally chase away any third party that might arrive. These chases may take the birds clear out of sight out over the ocean. Particular birds prefer a certain reef for foraging and may be there several days in a row, but others may come in and three or more birds may feed in the same spot during the course of a day.

These herons experience difficulty in getting food at high tide, and may spend a lot of time getting little or nothing from the sand-clouded waves at this time. If there is a high tide at dawn, they sit around and wait for the water to drop, after some futile efforts at foraging, or they may try their hand at catching skinks up in the vegetation. I have watched them thus catching Emoia cyanura at Ine. Apparently they can get plenty of fish in a short time if the tide is low, because they will sit around motionless for long periods on the reef or perched on horizontal coconut fronds even when the tide is low - after their feeding. A stomach contained the following fish, such as are commonly found in lagoon tide-pools (these and all subsequent fish identifications are by Mr. Don Strasburg): 1 Gobius ornatus, 1 Goby sp., 2 Salavius lineatus, 1 Lutianus sp., 1 Acanthurus triostegus and a shrimp (Palaemonidae). A peculiar bathing habit was witnessed in which the bird squats for several minutes

in a pool, with just the head and shoulders sticking out. A single specimen was preserved; it had louse flies but no endoparasites.

Gallus gallus, Fowl, Kako (rooster), Lala (hen).- The fowl is found abundantly around human habitations. They were kept in pens only by the preacher at Ine, who had about 20 in a screened enclosure. These were terribly infested with parasites as a result of the ease with which their droppings could contaminate the food. Some fairly independent families of chickens are located several hundred yards away from the edge of town, and there was a large flock abandoned on Ijoen, where there is only a seasonal population of people (harvesting coconuts). There were no truly wild chickens such as are found far from humans in the woods and jungles of Palau, for instance. Chickens are eaten here only on special occasions, and the Arnoese don't like eggs. As a result, there appears to be a great excess of chickens over what are actually needed for food. They function in cleaning up wastes and scraps throughout the villages. I never saw them molested by cats or dogs. They eat seeds, ants, maggots, beetles (the entire insect fauna such as is found on the ground and in rotting fallen breadfruits), grass, leaf hoppers, skinks, and coconut meat. For the most part they forage on their own, but some people feed them coconut meat in the evening, along with all their other domestic animals. Parasites are abundantly found in these fowl: nematodes such as Ascaridia, Capillaria, Acuaria, tapeworms, and Protozoa such as Trichomonas and Entamoeba. Nevertheless the chickens which are not kept in pens appear to be hardy and robust, as well as prolific. There is plenty for them to eat, even without the help of humans, as evidenced by the healthy flock, including many young chicks, which followed at my heels all over deserted Ijoen.

Pluvialis dominica, Golden Plover, Kolej. (In the black breeding plumage it is called Kolej lakek).- The following applies to all five shore-birds found here: These shore-birds breed in the far north, and young and old alike spend the winter in such places as Arno. The following summer the adults go back to their breeding grounds but the immature birds remain on through their second summer and second winter, and do not even acquire the breeding plumage during this "over-summering" period. Thus all the plovers seen at Arno were immatures in residence for the entire period of the study, except for one seen on June 15, which was in breeding dress. However, by September 2, an influx of birds from the north was underway, as evidenced by many which were beginning a molt from the breeding plumage to the winter dress (new white feathers coming in on the black under-parts). A bird with ragged primaries occupied the stretch of sandy lagoon beach by our headquarters all summer, and was seen daily. About half a dozen of these birds are found per mile, along beaches, reefs, and inland in grassy or cleared areas or trails through the forest. They forage off and on all day, beginning very early (about 6 a.m. when barely light), becoming very active at dusk. They are heard in flight and are active on moonlit nights. They forage in the manner of a robin, on marine dipteran larvae (Tendipedidae), small nereids, small crabs, bits of seaweed, Halobates blown up on the sand; earthworms, etc. from inland. Plovers occur singly or in groups of 3 or 4 and may associate loosely with tattlers and turnstones to the extent that these three species may join in flight, but each pursues its own manner of independent feeding when they alight. Plovers are the most numerous of the five shorebirds, and are the least restricted in habitat. One specimen was taken; it was infested with mites, but the small flukes and larval tapeworms in its

digestive tract were probably from their food items.

Numenius tahitiensis, Bristle-thighed Curlew, Kowak.- I saw only eleven of these birds; they were restricted to areas of broad gravelly tidal exposures as found on the north and east horns of the atoll. They were probably around all summer but not detected until I visited such areas July 29 - August 25. The curlew feeds on crabs - it grasps one in the tip of the long beak, raises it high in the air (over the bird's back) and whacks it down on the rocks, picks it up again, and repeats the performance until the crab is dismembered and can be swallowed.

Limosa lapponica, Godwit.- Only one was seen, at Pikaareji on August 25, probing energetically with its long straight bill into the soft sand of an exposed tidal flat. It was probably seeking various invertebrates as food. It could have been an over-summering bird or a newly arrived migrant from the north.

Heteroscelus incanus, Tattler, Kidir.- The tattler is found on rocky reefs throughout the atoll and is usually solitary, but sometimes two may be seen together. Not until August 25 was a flock seen (6), possibly consisting of newly arrived migrants. Although no breeding would take place at Arno, a mating flight was seen on August 3: two flew high in small circles over Ine Village, a couple of feet apart, uttering continuous calls. They forage on rocks at the edge of the water, and only rarely at very high tides will they get along the sandy beach. One was watched thus pursuing the very swift Ghost Crabs (Ocypode ceratophthalamus). With the aid of its wings, the bird was able to run as fast as the crabs, and would follow them into the wavelets, but it was impossible to see if it actually

caught any of them. It probably did, for it kept at this type of foraging, strange for this species, for a half hour, and could not be seen at close range nor collected, because people kept coming out on the beach to perform their morning functions, thus scaring the bird farther and farther away. Since for the most part they are strictly confined to rocky exposures, they come into contact with turnstones more than with other shore-birds, and though they may fly with these turnstones, they forage independently. They begin their activity at the crack of dawn (about 6 a.m.), and are commonly heard in flight over reefs on moonlit nights. These birds are widely spaced, but constant in occurrence - one on almost every separate patch of reef, or at least a couple per mile.

Arenaria interpres, Turnstone, Kötköt.- It was difficult to determine the length of beach patrolled by individual shore birds, but at least they were often seen making long flights from one exposed reef to another. With the Kötköt, however, a flock of four was around Ine Village all summer, and it roamed over at least a mile and a half of beach. By August 29 and September 2 an influx of new birds from the north was indicated by flocks of 11 and 14 respectively, around Ine. The habitat of the Turnstone is rocky coral shores, but it prefers smooth coral pavement or flat pebbly areas where it can run along and "tip up" to catch its invertebrate food. Dr. Hiatt identified invertebrates found in stomachs of this and following species. A stomach of a Turnstone contained small crabs: Dacryopilumnus rathbunae and xanthid crabs such as found in rocky upper tidal reaches. At the time that a Tattler was chasing ghost crabs on the beach, the Turnstones were attracted to the scene and attempted to copy the Tattler in chasing these swift crabs. With their short legs,

however, they were unable to get anywhere with these crabs, and finally gave up and sat around watching the energetic Tattler.

The Turnstone is definitely gregarious - solitary birds are only temporarily away from the flock. They are caught alive and used as fighters by the Arnoese. A group is found every mile or so of reef. Parasites of the single specimen taken were mites, slender nematodes from the stomach wall, large flukes and tapeworms from the intestine, and flagellates in the caecum.

Sterna sumatrana, Black-naped Tern, Keer brik.- This small tern is found abundantly where there are sand spits or gravel exposures (for resting) near large expanses of shallow water (for feeding). As many as fifty were seen together. Adults, immatures and juveniles could be recognized by their distinctive plumages, but there were no newly-hatched juves to be seen, indicating that nesting had taken place prior to our study. A flock of nine was around Ine Village all summer; in a good noddy fishing flock, these would be joined by others coming in low and straight from great distances, attracted by the milling noddies. The nine used to make a circuit of the anchorage each morning at about 6:50. They forage by diving from about 25 feet above the water, but sometimes swoop low trying to catch small flying fish in the air. They do not poise before the dive (as do the Crested Terns), but plunge right in with no wasted motion or time. They gather at favorite reefs as they are exposed by the tide and spend a lot of time sitting there on the rocks at the water's edge, often joined by Crested Terns. Two specimens were taken; their stomachs contained the clupeid Stolephorus delicatulus, the herring-like fish sought by Sterna and the noddies when driven to the surface by tunas. There

were no parasites except bird-lice and mites.

Thalasseus bergii, Crested Tern, Keer möt.- These giant terns feed on mullet, the clupeid Harengula ovalis, and sometimes chase flying fish. They hunt by diving from a height of 25 to 75 feet as follows: a bird over a favorite shallow water fishing site swings into the wind, poises and rises, suddenly faces down and rolls about a half turn as it plummets down to sink half under the water, rises into the wind, swallows, shakes out its feathers (clearing them of water), flies straight on, then circles back to the starting point. One group got only one fish out of 11 dives, another morning they took 6 fish out of 9 dives. Prodigious distances are covered in foraging, and single birds can be seen in the middle of the lagoon, bound from one end of the atoll to the other. They are widely distributed in the lagoon, but do not go far out over the ocean. They do not join the noddy fishing flocks, but feed on their own or in company with Black-naped Terns. They are active from dawn to dusk, but spend much time sitting together on rocks. Two adults and 3 immatures were usually around Ine Village; sometimes others joined them to augment the flock to 9 or 11. One specimen was taken, which, for parasites, had only mallophaga and mites.

Anous stolidus, "Large Noddy", Rabit.- These birds were seen on the ocean between Arno and Majuro and in various parts of Arno Atoll: a few at Arno Island, Pikaareji and Autore, many along the western part of Ine Island, and huge concentrations from Nameji to the eastern extremity of the atoll, where they vastly predominated over the Small Noddy. Big fishing flocks were observed in the latter area, where they differ from Small Noddy flocks by their continual whining cries. The night (no moon)

was made hideous by their growling and shrieking at Rakaaru, where they flew around the trees all night. The next morning they were all sitting around roosting in palms, in two large concentrations. One at Autore acted menacingly, as if it were protecting a nest, but I found no actual evidence of nesting at this season. One specimen was taken; it had no internal parasites, but in its plumage were mites, mallophaga and louse flies. The food consists largely of bait fish scared up by tuna.

Anous tenuirostris, Little Noddy, Jökar.- The various roosts where these birds congregate between feedings seem to have in common that they are on the smaller islands near extensive shallow water areas, and are in trees, from which the birds can keep track of the fishing flocks out in the lagoon or ocean, and join them at appropriate times. Large roosts were at Island No. 7, Tagelib (two, with old nests in breadfruit trees), Autore in Ochrosia and Scaevola, Nameji, Pikaareji (breadfruit), Dodo (Scaevola) and East Tagelib. There were small roosts at Mareri, Kirage, and Rakaaru (nine birds in a mangrove tree with an old nest). As indicated in my previous report, Noddies feed in large milling flocks on bait fish scared up by tuna. They scoop these fish from the surface as they hover or partially rest on the surface. They follow the movements of the tuna to new schools of bait fish, so they are always there when the spray begins to fly. Another entirely different type of foraging is indulged in individually - birds patrol the shores scooping small fish out of shallow pools. They thus cover vast areas in their feeding. This species is more abundant than stolidus, being overshadowed by the larger form only at the eastern tip of the atoll. Seven specimens were

taken; the food is Stolephorus delicatulus and small tide-pool fish. Parasites found were mallophaga, mites, louse flies, nematodes in the stomach, possible larval tapeworms? in the intestine, and flagellates in the caeca. Only individuals with large caeca have the flagellates.

Gygis alba, Fairy Tern, Mejo.- These were found in pairs or small groups around conspicuous broad-leaved trees where they roost at various times of the day and night. Their behavior is indeed mysterious, and never once did I see them feeding. Shortly after dawn I would see individuals and small groups coming in from the ocean. They were often seen carrying fish around as a display, but they seemed to spend all day calling, chasing and fluttering and roosting around inland breadfruit trees. One specimen was taken; it was carrying a dried 4-inch flying fish, Exocoetus volitans in its bill, and had in its stomach part of another flying fish and a hard shiny seed, which it may have picked off the water. The only parasites were mites. Though there was much chasing, calling and bearing of fish tokens, there was no evidence of nesting.

Ducula oceanica, Micronesian Pigeon, Mule.- For the distribution of the pigeon, see the accompanying map. Figure 2. It was absent from many suitable areas, but it might visit them at other seasons or other years in following the breadfruit crops. However, the natives knew of no such movements, and recognized them as present on Arno, Ine and the eastern horn of the atoll, and nowhere else! Some, but not all, of the individuals were definitely breeding during the summer. A nesting pair was observed incubating from July 1 - 18, but failed in its efforts and deserted the site by July 21. One bird would pick off coconut leaflets from dead fronds high in the trees and would pass them to the brooding bird, which would then incor-

porate them into the nest under her, in the axil of a coconut frond. There was very little such nesting material aside from the coconut cloth that naturally would be found at the base of the frond, for none projected into view.

Pigeons travel long distances from one breadfruit grove to another, and fly from island to island. From July 10 until the end of August, about 10 birds were daily seen devouring breadfruits in a tall tree in King Tobo's yard. They completely stripped this tree, but passed over adjacent trees. In addition to breadfruit, they were noted eating _Allophyllus_ fruit and papaya blossoms. Call-notes were to be heard as early as 5:45 a.m. and the birds are active in the breadfruit tree until about 6:30 p.m. Some are kept as pets by the people; they are recognized as being good to eat, but with the absence of guns, they are rarely if ever taken for that purpose. They apparently have forgotten the various primitive methods of capture. Two specimens were taken, and their only parasites were bird-lice.

Eudynamis taitensis, New Zealand Cuckoo, Udrej.- This solitary species spends its "winter" here and breeds in New Zealand. Single birds were seen 13 times in various parts of the atoll, always in dense forest. Only one was seen in the same area twice in succession, and it is likely that they roam over great distances. There is a rather set pattern of activity: a bird is usually first seen flying straight and swiftly through the trees; it alights on a dropping dead coconut frond, walks swiftly up it, sits very still for a long time, then leaps from frond to frond, spiralling upward into the crown of the tree, and finally flies off to another tree. Twice they were seen near the ground, where they would have to go in order to catch Ground _Emoias_. They display great agility in

leaping around in trees, as well as extreme stealth and secretiveness. A single specimen which was preserved had eaten a four- or five-inch Brown _Emoia_, 5 green katydids, and a roach. Flagellates were present in its long caecum.

Delphinus roseiventris, Porpoise, Ke.- The same school of about 20 individuals played for hours on sunny mornings off the edge of the Ine anchorage reef on various days from June 23 to August 22. Another (or possibly the same) school was seen off the edge of the ocean reef at the western part of Ine Island. Slate colored individuals with pink bellies caught by natives at Pikaareji had apparently been driven into the lagoon. Dr. Hiatt has a complete description of the fantastic manner in which they are taken alive. They are much prized as food, and various sewing devices are made from the jaw bones. I saw no porpoises inside the Arno lagoon. I noted a different type with a light patch on the back, half-way between Arno and Majuro on August 9. I have furnished Dr. Remington Kellogg of the U. S. National Museum with the skull and all my notes in the hopes that he will be able to identify for us the various kinds. Two specimens were examined for parasites, and I found only tapeworms; one large kind with head embedded in the lining of the rectum, and a second smaller kind in the duodenum.

Pig, Bik.- Pigs are eaten only on special occasions. Where they are not penned in, they tear up everything including the flagstones that mark the roads, and all the smaller vegetation. This destruction was seen at the southeastern portion of Ine. Usually they are kept in little log pens at the edge of the lagoon beach, and must be fed scraps and coconuts.

A great abundance of parasites were found in the nine stools examined: the protozoans Entamoeba, Trichomonas and Balantidium, and numerous nematode worms, not all identified yet, but including several pathogenic species as well as Trichuris. (These Trichuris ova had a somewhat different shape from those found so commonly in human , and doubtless represent a different species.)

Cat, Kuj.- Strange to say, I found no feral cats out in the woods, though I did see them stalking rats out along the trail at the west edge of Ine Village. A female brought two rats within an hour to her nest under our house. They also eat breadfruit and coconut meat, and stand around waiting their turn when the chickens and other animals are being fed coconuts in the evening. They seem to be on friendly terms with the chickens and dogs and pigs. They are common pets, and appear to be of great use in Ine Village because they catch house rats. All are rather thin and scrawny, and the lighter colors predominate in their mixed stock.

Dog, Kiru.- Abundant around houses; none noted far from human companions. The dogs at Arno were of robust construction, and were all pretty much the same in form, and were mostly short-haired varieties. They find cool places to lie, preferring the soft sand dug up by crabs along the shady road; here they spend much of the day, each in its own favorite couch. There were very few females around Ine Village, and naturally each rare entrance of one caused a sensation! Also there were few pups in evidence - most of the dogs there were old battle-scarred veterans who lived in the hopes and expectations over their daily battles.

They are friendly but rather independent. One particular large one was a companion of the group of children who used to bring us specimens. He would bark and hunt with them, circling through the undergrowth when they were out hunting lizards and rats. He often scared away the herons that I was studying, and delighted in chasing birds along the beach. These dogs eat coconut meat along with the other domestic animals, and do not catch much of their own food. On Majuro, however, they roved in packs along the beach and were said to corner and catch fish cooperatively from tide-pools.

Rattus rattus, House Rat, Kijirik.- I found this rat only in and near Ine Village, but it is said to occur on a couple of islands between Dodo and Tagelib. These are the only places where green coconuts are cut into and eaten by rats; since the Polynesian Rat is found so abundantly all over the atoll in places where green nuts are not eaten, this is another line of evidence to aquit the dainty Rattus exulans of this offence. I trapped house rats on the ground, and also shot several from coconut trees at night; beneath these trees the ground was strewn with green coconuts in which a hole had been gnawed permitting the rats to enter and clean out the inside meat. Arnoese stated that this species had been rather recently introduced by the Japanese, and that before that time, no green nuts were eaten. My House Rat specimens are of diverse coloration, one being dark grey, indicative of admixture of native (?) island stock and Black Rat stock, the latter probably introduced from ships. These rats did considerable damage to stored copra and food in the Ine store and warehouse, and may be a contributing reason for the fact that the copra was always shipped out to Majuro as often as

possible. Two nests were found a few inches apart in a down rotten coconut log; one contained 6 young, the other, 3, identified as this species by their size. The nests and their location, however, were exactly like those of <u>Rattus exulans</u>, and the house rats either "copy" <u>exulans</u> in this respect, or have appropriated these nests from their rightful owners. Two unoccupied nests were found near the tree workings; they also resembled the nests of <u>exulans</u>. House Rats were sometimes seen out in the daytime; an indication that their numbers are great. None were found in my transect area about a half mile from the village. They are caught by cats in town, and some of the people set traps for them. It would be easy for the boys to kill them by placing husked coconuts (opened at one end) near their holes, waiting for them to enter the nut, then crack down on them with a club. Four specimens were preserved and sent to the National Museum. Stomachs contained coconut meat and green plant material. Two rats shot from trees in town had no ectoparasites, but others had mites and lice, but no fleas. There were abundant tapeworms and stomach nematodes and flagellates in the caecum. Rat tapeworms sometimes infest humans, but I found no evidence of tapes in the human stool survey.

The charge of eating green coconuts is a serious one indeed, and is already the cause of some concern to the people. (Coconut Crabs - see Dr. Hiatt's report - and Polynesian Rats eat only old fallen nuts, gleanings from the copra crop left on the ground because the people by no means take all the available nuts for copra. In fact they work the copra in a sporadic and rather disinterested fashion.) I think it would be easy to eradicate this rat from the few places where it has become established, by poison or trapping or by running them down with dogs whenever the piles of old coconut husks are burned. At least, those

whose trees are being damaged could easily contrive simple guards around the trunks.

Rattus exulans, Polynesian Rat, Kijirik.- This little rat is abundant and generally distributed even on some of the smallest islets. So many seen bouncing nimbly across the trail by day indicate tremendous numbers. They can also be seen climbing up and down trees, and poking around in the interior of the piles of coconut husks. The nest, a globular mass of soft dead leaves of whatever plants are handy (Pandanus, Polypodium, coconut cloth) about five inches in diameter is found inside of rotten logs, stumps, among the hanging dead leaves of Pandanus, and two were found each inside of a coconut husk. The rats are caught by cats. Near the nests, or on favorite eating places in Pandanus trees, eaten seeds of Triumfetta procumbens accumulate in piles. As determined by a microscopic comparison of stomach contents and coconut blossoms, they eat coconut blossoms, and are often seen at night climbing in the flowering stalks. Their main food is fallen coconuts. In spite of their abundance they have little if any influence on the copra production for only a small part of the available nuts are ever harvested.

My Ine friends, with whom I travelled to several islands, in an effort to be of help in my lofty researches and deliberations, would entice these tame little rats out from the piles of husks by strewing freshly opened nuts around. Within a minute or so the rats would come out, attracted by the smell, to be greeted with a rain of blows upon the head. My friends would then come to me, triumphantly bearing rats whose heads were reduced to pulp. No amount of explanation sufficed to get them to change their aim; apparently a block is involved, for when

they try to hit the rat elsewhere, they miss altogether. Thus I got measurements 17, and saved only 7 which had good skulls (trapped or shot at night). These specimens had mites and lice, flagellates in the caecum, whipworms threaded in the stomach lining, larger nematodes in the stomach, tapes in the intestine, and abundant ova of tapeworms and nematodes in their droppings. No biting true bugs (such as commonly carry blood diseases of rats) were found in the nests.

<u>Homo sapiens</u>, Man, Armij.- The predominant vertebrate on land, but far outnumbered by several species of lizards and by the Polynesian Rat. Signs of his activities are roads, trails, piles of defunct coconuts (the most important habitat of the smaller skinks, geckos and rats), artifacts such as baskets washed up on the beach, steps cut on coconut trunks, houses, etc. Man's main influence on the rest of the land animal and plant world is the clearing of undergrowth to facilitate coconut growth, and the burning of this trash. Thus the inhabited islands are very open (below the coconut and breadfruit canopy), an extreme of which is seen at Dodo, which is just like a park. Dodo also has the most modern type of dwellings and is the principal sea-port.

The thing that impressed me most about these people, aside from their friendliness, courtesy and generosity, was their intelligent interest in our projects. Unlike many native people in other areas where I have collected birds, they did not stand around and gawk at what we were doing. They actually understood what was going on, and furthermore, knew <u>all</u> the animals and plants, not merely by name, but in considerable detail as to natural history.

Concerning parasites, the following is the result of the Whidbey Survey at Arno and Ine Villages, May 2 and 3, 1950, respectively:

Arno: 126 stools, 110 negative, 9 hookworm, 6 *Trichuris*, 2 *Giardia*.

Ine: 127 stools, 98 negative, 2 hookworm, 12 *Trichuris*, 1 *Enterobius*, 9 *Giardia*, 2 *Trichonomas*, 7 *Chilomastix*.

My own survey of 100 stools from Ine Village was conducted with the assistance of Dr. Abija, who collected the samples. I examined a direct smear and a salt flotation of each. I preserved 40 slides of protozoa for further and more exact determination. The following results then are final for the helminth ova, but may be amended later for the protozoa. Only 36 stools were negative, thus indicating fairly extensive contamination of food by human excrement (indirectly of course). Frequencies of various parasites and harmless inmates of the human intestine follow:

small flagellates	10
Trichomonas	14
Giardia (cysts only)	5
small amoebae	16
Entamoeba not yet identified	10
Entamoeba histolytica	12 (of which they were eating red blood cells in only three)
Entamoeba coli	13
Enterobius	1 (usually not found in stools, so this is not an indication of its actual prevalence)
hookworm	5
Trichuris	26

Only the three people with E. histolytica ingesting red blood cells would be liable to have symptoms or impairment of health (amoebic dysentery). Enterobius of course causes severe itching, but the hooks were not numerous enough to cause symptoms, Giardia and Trichuris are usually harmless, and the rest of the list is always harmless. All that these results show is that the mechanism for transmission of intestinal parasites is well entrenched at Ine, and that there is a reservoir of hookworm and amoebic dysentery which could spread if there would be a further lapse in the maintenance of sanitary conditions.

To summarize in another way, only 8 people out of the 100 had potentially pathogenic parasites, in the following combinations:

Lieonbad: Trichomonas, E. histolytica, hook, Trichuris.

Aikuj: E. histolytica with red blood cells, Trichuris, small flagellates.

Torta: hook, Trichuris.

Lini: E. histolytica with RBC, hook, Trichomonas, other flagellates, small amoebae.

Motodrik: Entamoeba coli, E. histolytica?, hookworm, Trichuris.

Kijeia: Enterobius.

Lawi: E. histolytica with RBC, Trichomonas.

Overton: E. histolytica?, hook, Trichuris.

General Remarks on Parasites

No protozoan or helminth parasites of the blood were found in any of the land vertebrates. There are fewer kinds of intestinal parasites here than in most tropical areas. The cause is doubtless the paucity of

animal life as compared with larger land areas, resulting in few or no intermediate or reservoir hosts, necessary in the life cycle of many parasites. The parasites that were found are almost all of the sort that need no intermediate host, and are passed directly from one infected person or animal to the next.

The reason that there are few human parasites on Ine, in addition to the above reasons, is that the people by custom defecate out on the reef where the tide carries away this excrement. There are certain well established customs and taboos dictating who goes to what part of the reef and with whom - certain relatives can go together, even if of different sexes, others cannot be seen in the act by certain relations, etc., etc., as probably expounded in Mr. Mason's report. However, our presence at the village upset this hygienic system. I was guilty of this as much or more than the others for I was always out along the edge of the island early in the morning looking at Reef Herons, etc. The people are very modest about being seen by us "civilized" folk, perhaps thinking that we would sneer at them for not using modern flush toilets! Consequently they would sneak out to the edge of the beach and defecate under cover of *Scaevola* and *Pandanus* trees, in places where the tide would not reach, and where the hookworm larvae possibly might be able to develop in the soil, and infect others who stepped there. Also the proximity of this material to places where food is being prepared would facilitate the contamination of food by cysts of *E. histolytica* through various agencies. Consequently my recommendation for preventing a general outbreak of intestinal parasites on Arno is that we stay away from the villages as much as possible, that we try not to interfere with and try

to encourage the maintenance of the venerable customs of these people. There are some difficulties here because the people are envious of certain of the trappings of our civilization. But I think it is easy to convince them to have a respect for their own customs, especially in this matter of sanitation, as I have tried to do, actually, at Ine. I do not mean to imply that we should turn back the clock and attempt to shield these people from our influences. That is impossible. "Civilization", for better or for worse, (mostly, in my opinion, the latter), has reached them and has been influencing them for a long time. But as an immediate practical measure on Arno (facilitated by its distance from a hotbed of western civilization at Majuro), is to encourage the people to continue their own sanitary customs. The few stinking privies that the Japanese built at Ine will soon fall from sheer weight of termites anyway; they are little used.

Lest it be thought that this is all idle speculation and worry over nothing, permit me to dwell upon the situation at Majuro, that is, the island upon which the naval base is situated. Hookworm and pinworm (Enterobius) are rampant there, to such an extent that the naval doctors were actually considering mass treatment for hook. The dependents of naval personnel are almost all infested with pinworm, and have constantly to be treated for that as well as for hookworm. I believe that in addition, some Ascaris has turned up there. There is a large native population there, unusually (for the Marshall Islands) crowded. There is not enough privacy for them to indulge in their traditional practices of defecation, nor, apparently, are there enough facilities and/or knowledge of their use, to accommodate them according to civilized standards. The result, judging from what the doctors said about the

incidence of hookworm and pinworm, is just about a complete breakdown of sanitation, and immanent probability (if not already) of building up enough hookworms in people to cause actual symptoms of the disease. This consideration touches close to home, for Ine Village is only a day's sail from Majuro. In fact, I judge that the Ine people who have hookworm probably picked it up at Majuro or some other island, because the situation at Ine (except during our stay there) is absolutely contrary to the interests of the hookworms.

Termites

I found three species of termites at Arno. They occur in tremendous abundance, and play a most important and extensive role in breaking down all wood, dead branches and trees, stumps and logs, on the way towards its final reincorporation into the soil. It is practically impossible to find a piece of dead wood that is not riddled with termites. If you need wood for most any purpose you have to cut it green. It is of interest here that the earthworms also operate on the wood, though at a stage subsequent to the termite work. Taking coconut stumps as an example, the termites work in it while it is still sound and dry, a different kind of termite works in the damper portion and eventually the whole interior becomes damp and punky and rotten from the activities of a host of organisms. The worms work in this soft punky mass, where they are found in tremendous numbers. Of course the damp climate of Arno promotes the decay of wood by rot, fungi, etc., and the termites open it up to facilitate this process. Of the three species found, one is a very large form which is found in dry wood above ground, such as dead branches of <u>Scaevola</u>. A small, fast-moving kind is in damp wood

at the ground level, and may even work at the bottom of piles of coconut fronds. A small, slow-moving species, a miniature of the first, is found in the most sound wood, particularly erect coconut snags and buildings. Three species was more than Dr. Kirby expected to be found here. I made numerous slides of the flagellates in their hind gut. The community or "faunule" of various species of flagellates is different for each kind of termite, and thus comprises a useful indication of the course of evolution of their termite hosts. It is the action of these flagellates, either alone or perhaps in conjunction with associated bacteria, which makes possible the digestion of cellulose in the termite. Without them, the termite starves.

An additional note on the earthworms: these are much more active or muscular than those with which we are familiar at home. They can twist and squirm so violently when disturbed that they can actually jump several inches into the air. I watched a Golden Plover trying to kill one and the bird had great difficulty in keeping its grasp on the large worm, and could hardly subdue it. Ground Emoias eat the worms, for I saw a Black one with the end of a large worm projecting from its mouth. (Long worms must be swallowed gradually, as fast as digestion at the other end will permit.)

Time of Activity

Rain is very frequent here, and does not impede the foraging activities of most of the animals, except skinks. The small species of skinks definitely preferred the sun. Dasia was sometimes out in great numbers in the rain, at other times a sudden shower would send them all into hiding. I have considerable data on the time of appearance

in the morning of the various birds, of which I submit this record of August 4th as a representative example: (Ine Ancorage)

6:15 a.m. Pigeons barking in breadfruit tree (getting light)

6:20 and 6:45 Brown _Emoias_ still dozing on their roosts

6:30 Pigeon in flight, Plover flies across the island

6:40 Tattler foraging on reef

6:50 Two Fairy Terns coming in from ocean, a small Noddy patrolling the shore.

7:00 - 7:10 Crested Terns, Herons, Golden Plovers and Black-naped Terns now feeding.

6:25 p.m. Brown _Emoia_ and three _Dasias_ roosting

6:30 Polynesian Rat ran across trail

before 7:00 Two House Geckos out

7:00 (getting dark, turn on flashlight and shine:)
Big Geckos on all palms, Rock Geckos and House Geckos.

Noddy Terns fly around their roosting areas all night, shrieking and snarling; the shore birds call and fly on moonlit nights, and probably also feed (the Plover has a relatively large eye, permitting activity at night). Usually the shorebirds are the first animals to be heard in the mornings, their calls beginning at 6 a.m. when it is just barely light.

Seasonal Behavior

The shore birds and the Cuckoo are seasonal visitors here, and do not breed in this area. The Terns are undoubtedly permanent residents, but no evidence of breeding at this season was found. Old Noddy nests were seen, and some of the terns occasionally engaged in display flights. (In 1944 I found Noddys of both species nesting in large colonies at Eniwetok in October.) The only birds actually breeding during the

summer were Reef Herons and Pigeons, but only a few pairs were involved; the bulk of these populations probably breed at other seasons. Recently there has been intense interest in breeding cycles of oceanic birds, stimulated by Richardson and Fisher's work at Oahu, and well summarized in the most recent number of the American Scientist (1950, vol. 38: 613 - 616). Unfortunately, my data from the limited avifauna of Arno is negative evidence only; it would require a longer period of residence there to round out the story, which I might add, would be very worthwhile.

The lizards and rats breed probably continuously once they achieve adulthood. Ripe eggs and embryos (respectively) and young were seen all during the summer. All fully adult males had gonads of maximum size.

The "Hectare"

I laid out a study area on the narrowest part of Ine Island, a half mile west of Ine Village. It was a transect from ocean beach to lagoon beach, 43 yards wide (parallel to the beach) and 54 yards across the island (measured from the limit of vegetation on each side). Thus it included 2322 square yards of vegetation. I mapped out the plants, Konto identified them, and I entered on several duplicate sheets each vertebrate found so as to give an idea of their abundance and relative numbers, (see (Figs. 3 & 4) accompanying map). The vegetation consisted of a fairly continuous canopy of medium-sized coconut trees, _Pandanus_, and _Scaevola_ thickets. In addition there were a few small or medium trees of _Messerschmidtia_, _Morinda_, _Guettarda_ but no breadfruit for a half mile in either direction. Part of the ocean side was clear and rocky, part of the lagoon side clear and covered with short grass, the rest was covered with thickets of vines: _Triumfetta_, _Wedelia_ and _Vigna_. Other

small plants were the sedge, Fimbristalis, fern Polypodium (growing on stumps and logs), parasite Cassytha; Tacca, creeping grass Thurarea, milk weed Euphorbia chamissonis.

A trail cut through the middle of the area, on which people would walk or cycle from Ine to Jiyabo. A woman in the vicinity collected Scaevola flowers for garlands, and a man came through one day taking hermit crabs for bait. He had a club and a gallon tin; he would poke aside the skirt of hanging dead leaves on each Pandanus and rake out the crabs with his stick and put them in the can. Like the people, a Pigeon and a Cuckoo came across the "hectare" on the way to Jiyabo from Ine Village. Terns, shorebirds and herons worked the edge of both beaches. The following are the numbers of land vertebrates found:

Rock Gecko	4
House Gecko	8
Big Tree Gecko	25
Four-fingered Gecko	1
Dasia	8
Emoia cyanura	18
Brown Emoia	4
Rattus exulans	7
Total:	75 vertebrates in residence on the plot.

These figures represent minimum numbers, such as found in a rather unfavorable environment. There was only one pile of old coconuts, and no breadfruit trees; these form principal concentration points for skinks and rats, and occur more numerously elsewhere. A transect at the ancorage point near Ine Village would yield double the numbers for each species.

General Remarks on Carrying Capacity

The lizards and Polynesian rats occur in such abundance that it can safely be said that they have saturated their available environment. Though the fish supply could support many more terns and herons, they are probably limited by available nesting places during whatever seasons they nest. The Micronesian Pigeon is absent from several areas that look like perfectly good pigeon habitat. My guess is that rats hold down their numbers by raiding the nests. Nesting time is a very critical one for pigeons; they have very flimsy nests which are likely to be blown down by wind, and the fact that these particular pigeons nest in coconut palms, in which rats spend so much time, leads me to believe that the rats could very well prey on the eggs and nestlings. At least it can be said that the pigeons are not parasitized and are not hunted nor persecuted by man. I have no direct evidence to support my speculation on rats vs. pigeons, but the one nest that I was able to find all summer certainly did wind up in disaster from some cause.

The reasons why Arno has so few kinds of resident land birds (only two - the heron and pigeon) is that it presents little variety in habitats for land birds. This is more important, I think, than the fact that Arno is far removed from areas with large avifaunas from which it might be colonized by additional birds. If we compare it with Ulithi Atoll, situated near the Marianas and Yap, we find a comparable paucity: Ulithi, providing similar monotony of habitat as Arno, has only the Reef Heron, Micronesian Starling (?), and for mammals, apparently only the Fruit Bat and House Rat.

Concerning the oceanic birds, possibly more kinds will be found breeding here than the five species of terns. But many kinds of oceanic

birds are prohibited from nesting here by the absence of high ground. Several of the kinds need cliffs for nesting, and high rocks jutting from the sea, from which they can take off. (Many are unable to get underway in the air without a preliminary glide off some high point.)

The House Rat is still circumscribed in its distribution and abundance. It is hoped that it can be prevented from further spread, which would be a hazard to the copra crop. Man and his domestic animals are the land vertebrates for which Arno is most understaffed. I doubt if even half the land area of Arno is settled, and of the settled portions, only a portion of the available coconut crop is utilized. Most of the nuts sprout or rot upon the ground. Breadfruit is used to capacity, and there is some disease of the fruit that is reducing its availability. But there are many parts of the islands wide enough for breadfruit to grow, in which few if any trees exist. As stated in my previous field report, the rich supply of marine food is almost untapped. There is more than enough water, fish, coconuts and land for the present population; also, as pointed out under my account of pigs and chickens, there are many more of these domestic animals than needed. The introduction of rabbits, ducks, turkeys, goats, etc., would give them more variety, but with the present population would not fill a crying need for more basic food sources.

Concerning food cycles of the land animals, the "law of the jungle" is not much in evidence. Beginning with vegetation eaten by insects, the insects are in turn eaten by the various lizards, and here we come to a dead end, as far as the bulk of the lizard population is concerned, for relatively few of them are eaten by cuckoos, chickens and herons,

all of which have as their principal food, some other source than lizards. Again beginning with vegetable food, it is eaten by rats. Here again is a dead end, for the rats are eaten by cats only near human habitations.

Because of the paucity of land animals, we do not find an over-all food chain, or chain of interdependence.

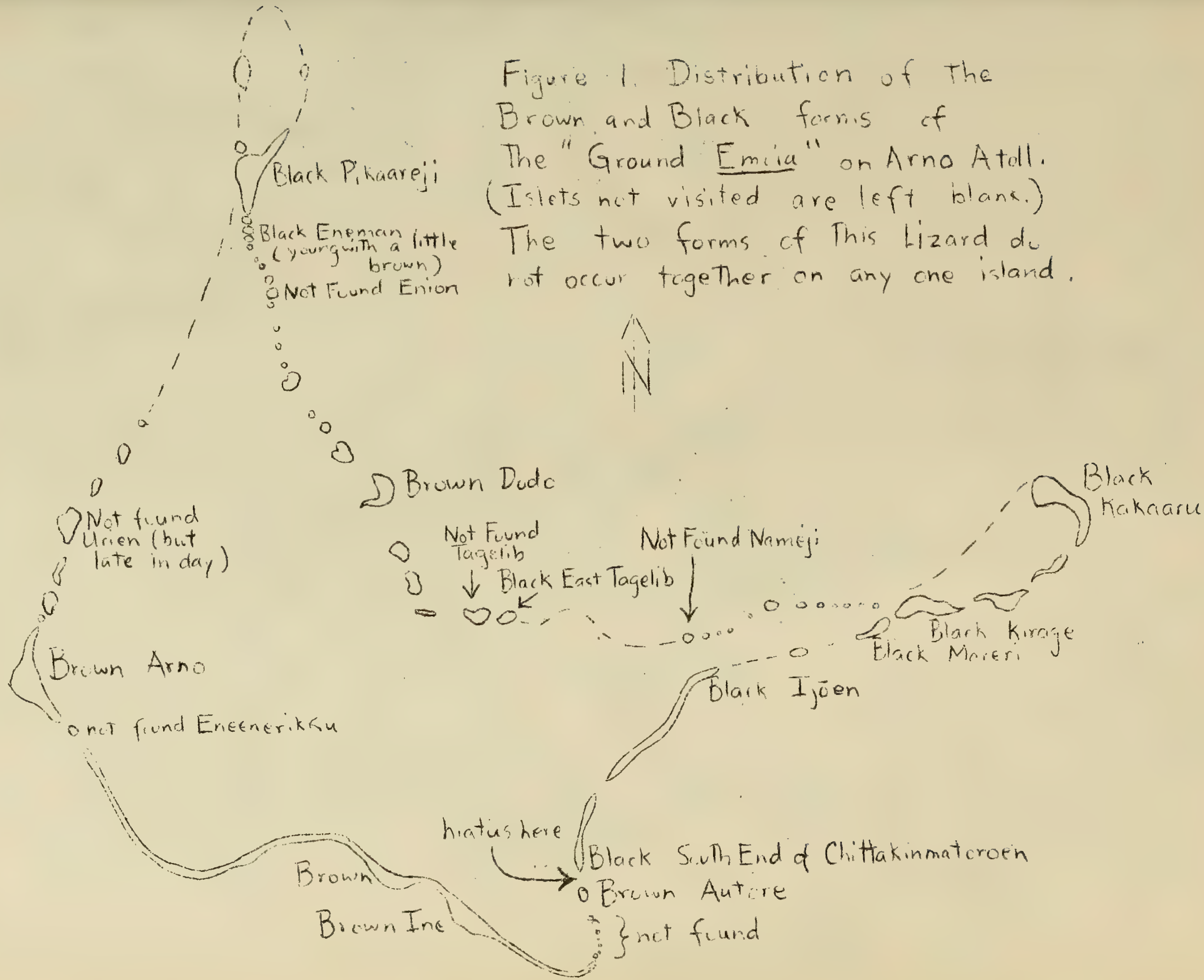


Figure 1. Distribution of the Brown and Black forms of the "Ground Emoia" on Arno Atoll. (Islets not visited are left blank.) The two forms of this lizard do not occur together on any one island.

Figure 2. Distribution of The Pigeon, *Ducula oceanica* on Arno Atoll.

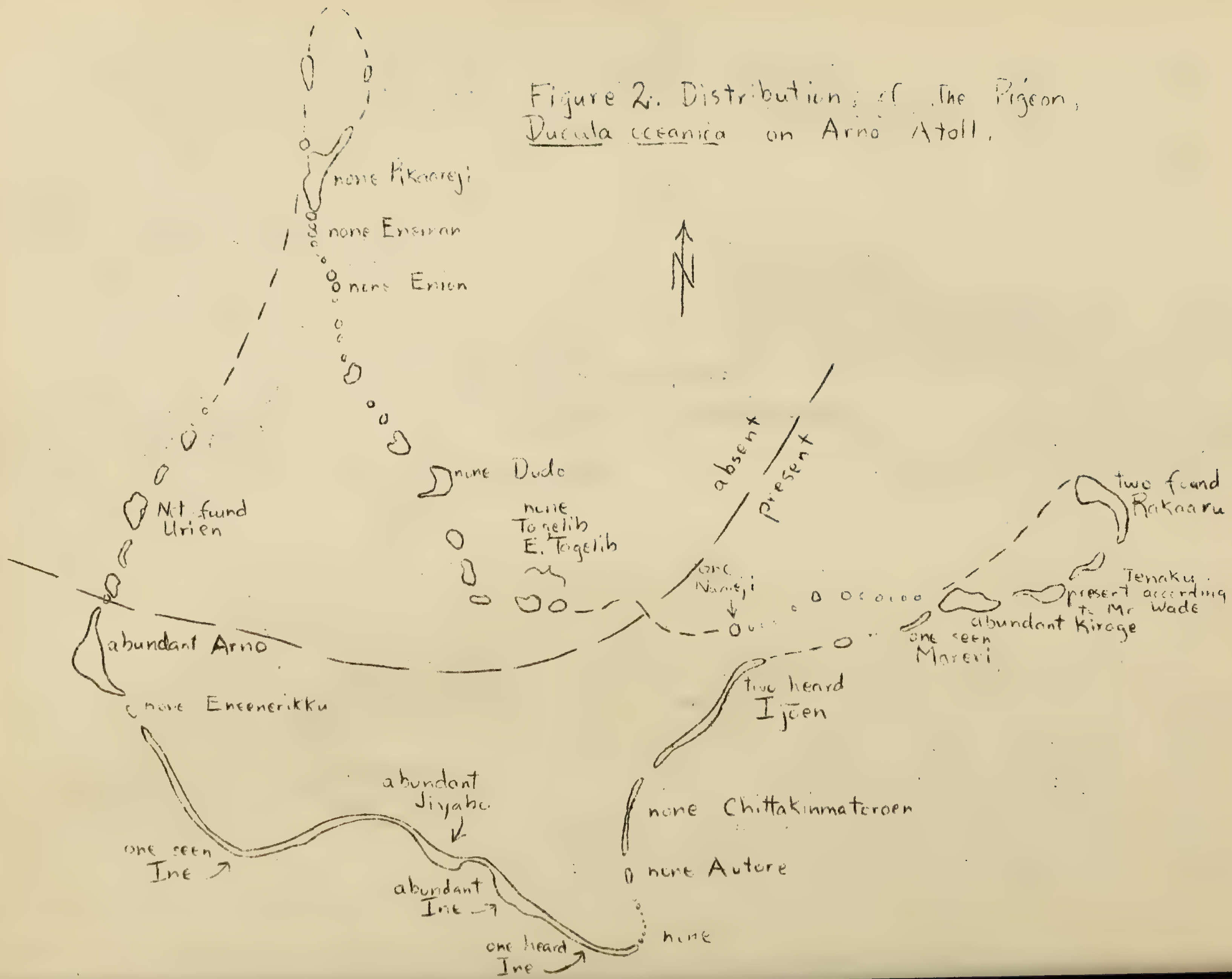


Figure 3 Plants and Gecko Lizards of The "Hectare."

R "Rock Gecko", _Gymnodactylus_
T "Big Tree Gecko", _Gehyra_
4 "4-fingered Gecko", _Hemiphyllodactylus_
H "Small House Gecko", _Lepidodactylus_

Coconut Palm
" stump
" log
" husks
Pandanus
Dead "
Scaevola Thicket

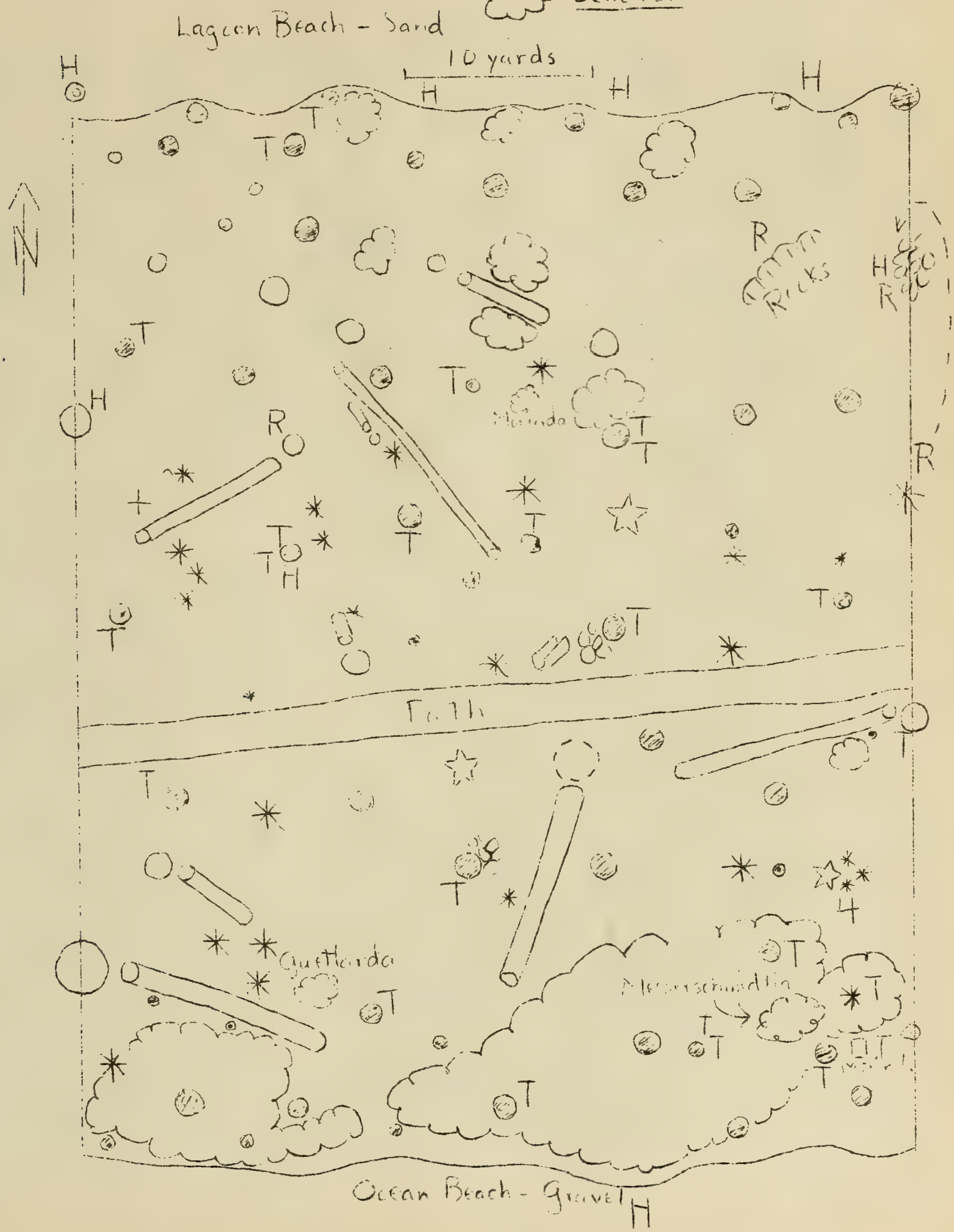
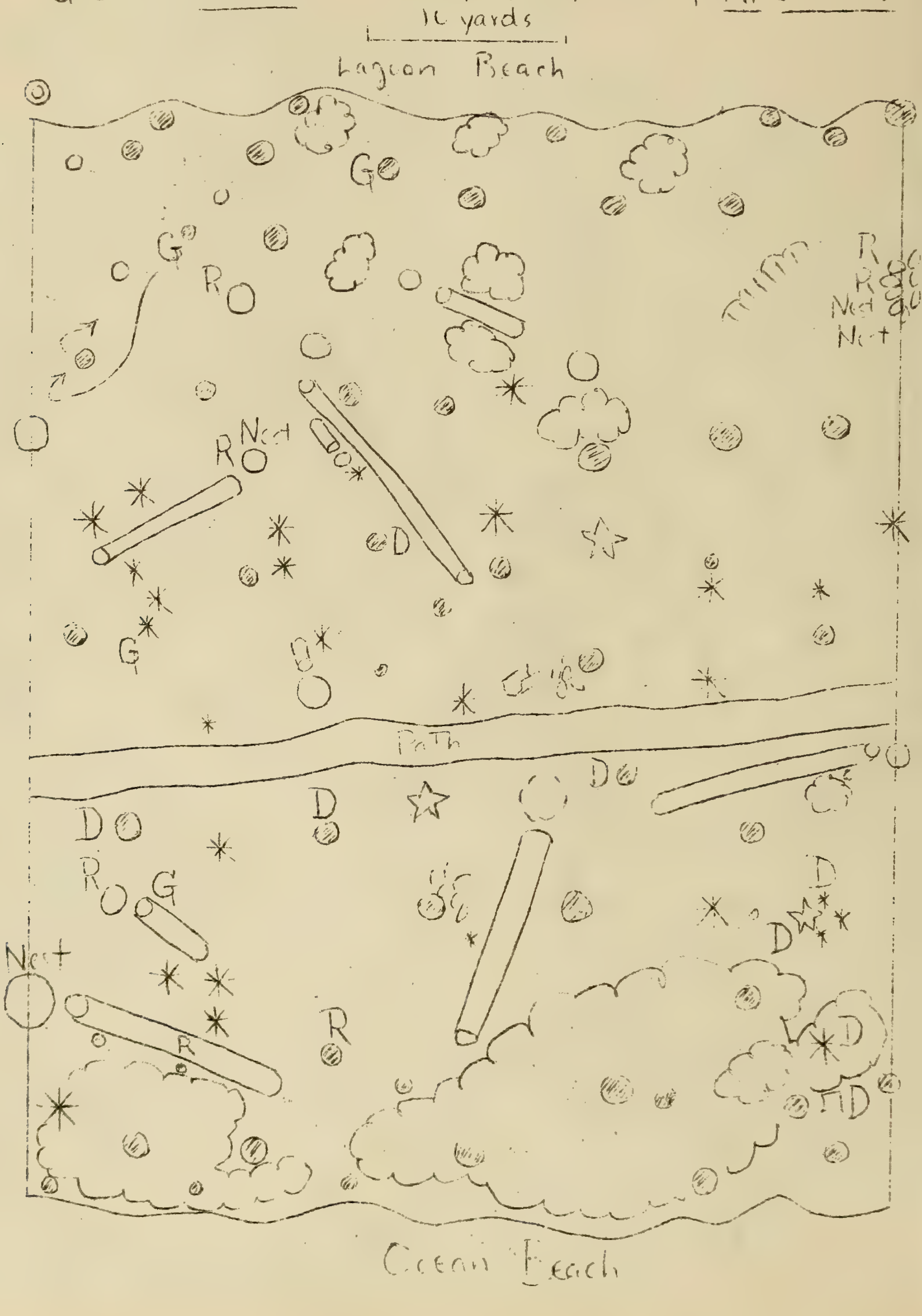


Figure 4. Skinks, Rats and Rat Nests of "Hectare"

Emoia cyanura not shown — 12 were present on ground and in vines

D *Dasia smaragdina* R *Rattus exulans*

G "Ground *Emoia*" Nest Nest of *R. exulans*



ATOLL RESEARCH BULLETIN

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MARINE ZOOLOGY STUDY OF ARNO ATOLL,

MARSHALL ISLANDS

SCIENTIFIC INVESTIGATIONS IN MICRONESIA

Pacific Science Board

National Research Council

Robert W. Hiatt, assisted by
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University of Hawaii
Honolulu, Hawaii
December 1950.

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Especially helpful in numerous ways were Commander Kenney, Ensign Dodds and Mr. Ben Kessler on Majuro, and Commander Avila on Kwajalein. The many ways in which Miss Ernestine Akers, Honolulu secretary of the Pacific Science Board, assisted in arranging for this project were greatly appreciated by the entire personnel.

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To all of the above who contributed to making the research described in this report possible I wish to express my gratitude and appreciation.

TABLE OF CONTENTS

NATIVE USES OF MARINE PRODUCTS

Subsistence or Food Resources

Species Used

Approximately 175 species of fish and invertebrates are used for food by the Arnoese. The exact total may reach 200, but the most important species involved are included in the 175 which were seen and identified both by their scientific name and by the local Marshallese name. Frequently, differences between Radak and Ralik names were noted, so to avoid confusion a policy was established to adhere only to the Radak name. Lists of these species will be presented in the technical reports.

Very few of the species used are of seasonal occurence. This results, in part, from the nearly total lack of fishing for pelagic fish with migratory habits such as the tunas and spearfishes. The fish and invertebrates usually taken are present in the lagoon throughout the year, although lunar phases, tides and spawning season do influence fishing activity for certain species.

There is a surprising lack of conservation measures and tabus relating to the marine species. In times past certain fishes, e.g., the mole (Siganus rostratus) were reserved for the iroij, but such practices have been largely discontinued, except for certain choice parts of some fish. No seasonal restrictions or minimum size limits are invoked. The absence of such restrictions most certainly stems from the abundance of food fishes available.

No species are reserved for special occasions, although the fishing methods involved preparatory to a large community celebration largely determine the species which will be caught and consumed. In general, it

appears that "occasions" arise following a very successful fishing operation, rather than before the fishing activity.

Catch statistics

As was noted in the initial Field Progress Report, catch statistics as such are impossible to secure because fishing is a family enterprise and is not entered into commercially on Arno Atoll. The only opportunity for determining the catch was to keep several typical families under observation to ascertain the amount of sea food consumed per person. Data of this sort are extremely difficult to secure because of the variable fishing activity between families and with time, coupled with the fact that interviews on such subjects are far from satisfactory. Some data are available from the Anthropologists of this Project who lived for periods with native families. The data available will be set forth in the technical report. It suffices here to mention that fish is, in general, a staple food item, and, if available, is eaten at every meal. The consumption of sea food probably averages one pound per day for each person.

Methods of collecting and fishing

The fin fishery on the lagoon reef is by far the most important to the Arnoese. A rather complete description of all the gear and its use has been compiled for inclusion in the technical reports.

Stone traps erected on the lagoon reef or on reef passes between islands are frequently met. The position and construction of each trap is designed for certain fish species. Their production varies from place to place, but in general the traps are very successful. The village of

Lōnar, for example, maintains a series of five traps which supply the population of 50 to 60 persons with all the fish needed.

Wooden stick traps of the type used generally throughout Micronesia are set out on the reefs by individual families.

Aside from its use in throw nets, flying fish nets, the square ukonjabuk net and bonbon net, regular cord netting is seldom used. Most of the seining methods are accomplished with coconut fronds built into leaf sweeps of various kinds and dimensions. Seven different methods of using leaf sweeps were recorded in detail, and the chief fishes taken with each have been listed. Some trolling for tunas and carangid fishes is done with wooden plugs to which chicken feathers are tied so as to resemble the common feather jig used by sportfishermen. In times past trolling lures were fashioned from the shell of the pearl oyster, but this is virtually a lost art; only a few of the old Arnoese remember how to make these lures. One built on our request will be described in detail in the technical report.

Many Arnoese are excellent spear fishermen and this method is one of the chief ones employed to provide fish for individual families. Spearing is done on both the seaward and lagoon reefs. Unlike American spears which are barbed and shot from an air gun or a rubber sling, the Arnoese spears are barbless and have firmly attached, slim wooden handles with a short rubber sling fastened to the handle. A long spear about 12 feet in length, a shorter spear about 6 feet in length, and a long gaff about 4 feet in length are carried by each spear fisherman.

Fishing poles made of wood from the _Premna corymbosa_ tree are used without reels. The short line is attached to the tip of the pole. These

are used at the edges of channels and at the outer edge of the reef where the line can be let down into deeper water. Most hook and line fishing is done from small paddling outrigger canoes, usually at the outer edge of the lagoon reef or over coral mounds rising near the surface from the lagoon floor.

Other fishing methods to be described in the technical reports include the ikaidrik (for Elegatis bipinnulatus), the jibke (for porpoise), the jaibo (for huge sipunculid worms), the erdroe (hand groping), the kaikikit (groping with a stick), the kawōr (treading), the kabwil (treading at night with a torch) and fish poisoning in muddy swamps by hydrogen sulphide and by the crushed fruit of the Barringtonia tree.

Except for fish hooks and some twine all the gear used in fishing is hand made by the Arnoese. A real lack in present fishing supplies is twine for fishing lines and for weaving nets. No special fishing vessels are used at Arno. The small paddle canoes are essentially just hand line boats, whereas, the larger sailing canoes are chiefly for transportation, with fishing operations secondary in importance. While many canoes are in operation on Arno, they are in short supply. Lumber from breadfruit trees and skilled canoe builders are not plentiful.

It was not possible to ascertain the catch per unit of effort because the time spent in fishing and the fishing trips were very erratic.

The fin fishery in the ocean is relatively unimportant to the Arnoese. Some trolling for tunas and some fishing for flying fish is done, but the total catch is insignificant.

There is no sea turtle fishery on Arno. The Green Sea Turtle is not common and the catch at infrequent intervals occurs by chance. A few

turtles have been seen to deposit eggs on the sandy beaches, but the observations are rare.

Among the invertebrate fisheries the molluscan species are the most important to the Arnoese. Certain gastropods of the families Strombidae, Turbinidae, and Neritidae are sought for food while cowries (Cypraeidae) are collected for the making of jewelry and for other ornamental purposes. Among the pelecypods the most important is Asaphis deflorata which is esteemed as food, and the shell makes a most useful scraper for various activities in the preparation of food. The giant clams (Tridacnidae) are not used extensively for food, but the small attached species Tridacna crocea and T. elongata are frequently gathered to fertilize the breadfruit trees. Native opinion on the use of the giant clams indicates that they are less desirable than fish for the table, and that the abundance of agricultural crops (breadfruit, etc.) at Arno makes it unnecessary to exploit all available subsistence resources on the reefs.

Land crabs, both brachyuran and the anomuran, Birgus latro, are caught and eaten frequently. An intensive study of the ecology of land crabs was made and will be presented in the technical report.

Holothurians are not used at Arno for any purpose although the reefs, typical of the tropics, abound with many species. The tremendous population density of Holothuria cinarescens on the lagoon reefs was investigated in detail and will form the subject of a special technical report.

No use whatever is made of the algae on the reefs. Unlike Polynesians, the Micronesians do not consume sea weeds, nor do they use it as fertilizer.

Methods of preparation of marine products

The methods of handling various food fishes for immediate consumption or for storage were recorded in detail. Large tunas and porpoises are butchered according to a stereotyped plan, the various cuts are given names, and the iroij portions are designated. A ll these observations will be described in considerable detail. Of note is the fact that the porpoise caught at Arno may well be a new species according to preliminary reports from Dr. David Johnson of the U. S. National Museum. The author has furnished photographs and ecological notes to Dr. Johnson. No marine species are prepared for export.

Use of marine products as fertilizers for agricultural crops

The only marine organisms used for fertilizer are the two small species of giant clams, T. crocea and T. elongata. These are used to fertilize breadfruit trees; the methods will be detailed in the technical report.

Use of marine products as food for domestic animals

The sole uses of marine products to feed domestic animals are fish for dog food and ghost crabs (Ocypode) which are fed to sows to increase lactation.

Tuna baitfish resources

Since baitfish resources may become the most significant marine income item to natives on atolls, a thorough survey was made of the baitfish available. Data were gathered on species present, population density, distribution about the atoll, ecology, and length frequencies. Several large

schools of dusumierids and clupeids were poisoned so that an examination of the reproductive condition, food habits and length frequencies could be ascertained. It may be stated here that baitfish resources are relatively great at Arno Atoll. Schools were frequently encountered which would supply up to 200 scoops of bait.

Poisonous species

Through interviews with natives approximately 15 species of fish were found to be poisonous. These included many of the fishes known to be poisonous in tropical waters such as Ctenochaetus strigosus, several species of Tetraodon, Canthigaster and Diodon, some scorpaeonids, Synancea verrucosa, Pterois, certain muraenid eels, and certain balistids. No seasonal differences in poisonous properties was apparent, but certain species poison on one side of the atoll were not poison on the other.

Use of uninhabited islets as a source of marine products

General observations showed that natives did not venture far away from their home island to fish, and the fish populations, as seen during long periods of skin diving with face plates, along the shores of uninhabited islets were definitely greater. It was apparent that the fish populations around inhabited islets, although sparser than around uninhabited islets, were still adequate to provide the necessary food fish in the time available for fishing. Thus, it is not necessary for the natives to go to uninhabited islets to fish. The fish resources around these uninhabited islets are definitely under-exploited.

Importance of marine products from the reefs and lagoon as compared with the oceanic realm

As stated previously, the reefs and lagoon produce virtually all the marine products utilized. The paucity of passes through the reefs, the location of all dwellings along the quiet lagoon shore and the distribution of canoes on the lagoon beaches preclude any extensive use of oceanic waters.

Implement and Ornamental Resources

Sponges

Sponges of commercial types are scarce at Arno, and, except for limited household use by the natives, are not harvested.

Shell jewelry

The Arnoese have never made shell jewelry for export. Some cowries were collected by parties of Japanese during the Mandate for use in jewelry, but no commercial exploitation occurred.

Other uses of shells

The use of pearl oyster shells for fishing lures has been mentioned previously. The shell of the pelecypod, *Asaphis deflorata*, is used as a scraper for many household uses, viz., scraping charcoal from baked breadfruit, scraping soft coconut meat from drinking nuts, and scraping bark off mangrove sprouts for the preparation of dye. The shell of the helmet conch, *Cassis cornuta*, is used as a scraper for cooked *Pandanus* fruit on a device termed the beka.

No shells have ever been exported from Arno for commercial purposes.

Rather than make a very general survey of the resources over the entire atoll, our study was concentrated in a small area typical of much of the atoll so that a thorough ecological account of life on an atoll might be obtained. Coincident with the detailed observations, a few field trips were taken to other important areas to view the resources and to discuss them with the inhabitants. Thus, a fundamental basis for comparison of other areas visited with our intensively studied area was afforded. For this purpose three transects were laid out, one across the sea reef, another across the lagoon reef and a third across Ine Island from the sea beach to the lagoon beach. Plots were marked off at 50 foot intervals on the sea reef and 100 foot intervals on the lagoon reef and across the land. Thorough collections of the animals present in each plot were made. Temperature and salinity were determined for each section under varied conditions, and the contours of the reef and coral tops were measured. The fish present in each section were collected by poisoning with rotenone so that a quantitative study of their abundance and distribution in relation to environmental factors could be made.

Species of corals present were collected and estimates of their abundance were made for each section. Drawings of these transects have been made showing the type and distribution of dominant corals present in each section. The vegetative cover and surface contours have been drawn for the land transect to show the ecological features significant in the ecology of land crabs.

Fish

As this report is written 310 species of fish have been identified and several additional species will result from more detailed examination of a few of the more difficult families. One or more specimens of each species collected has been returned to Honolulu for subsequent check on identifications and for use as a named collection to aid subsequent studies in the Trust Territory. This collection combined with the duplicates of fish species taken during Operation Crossroads at Bikini which were sent to the University by the United States National Museum and the collections made throughout the Hawaiian and Line Islands by staff members of the University and of the Pacific Oceanic Fishery Investigations provide what is probably the best fish collections for the Central Pacific. These collections will be made available to any qualified scientist working in the area. The 310 species now listed represent 60 families (following the classification of Berg). A total of 1197 fish representing 146 species were examined for their food and feeding habits. These data will provide the most comprehensive account of biotic interaction on a coral reef yet made. The gonadal development was noted on all fish opened for stomach examination. Thus, for approximately 1200 fish we have records on their standard length, sex, and gonadal development. Such data will be of great importance in estimating reproductive seasons and the age and size at maturity for fish in this latitude.

Considerable information on larval and juvenile development of reef fishes was obtained. Several series showing growth and pattern metamorphosis were taken, preserved and returned for study. For each species ecological notes were recorded to indicate its niche in the biocoenosis,

its preferred habitat, and its behavior patterns. Careful notes were taken on aggregating habits of many species.

Except for certain species of clupeids and dusumierids suitable for tuna baitfish, no other food fishes were taken in sufficient abundance to afford analyses by length frequencies. Consequently, the effects of fishing on the size and age structure and abundance of most species was not obtained. However, all species commonly utilized for food were present in abundance and in all size ranges known for the species. It is apparent from these observations that fishing intensity at Arno is not affecting the structure of fish populations in any way. Generally speaking all food fishes are being underfished rather than overfished and the reef and lagoon fisheries could be increased several fold without decreasing the yield per unit of fishing effort.

For the baitfish, Stolephorus delicatulus, Harengula ovalis and Atherina ovalaua, several large collections were made with rotenone so that length frequencies could be studied. From these data we are able to indicate the age groups in the population, the size range available in a baitfishery so that mesh sizes may be computed, and the abundance and location of the bait. These data are of great importance to any contemplated tuna exploration in the Central Pacific.

Turtles

The green sea turtle (Chelonia mydas L.) was the only species observed at Arno and this species is too scarce to be of any importance commercially or otherwise. The hawkshill turtle, Eretmochelys imbricata L., undoubtedly occurs at Arno but it is rarer than the green turtle.

There is no fishery for turtles, although the natives frequently catch them in the stone fish traps.

Invertebrates

Invertebrates of importance to the natives have been listed previously in this report. Plans had been laid to analyze species of the giant clams for size and age for the purpose of evaluating the effects of fishing on them. However, it was discovered that the most abundant species in the Northern Marshalls, _Hippopus hippopus_, was not common at Arno, while the larger species _Tridacna squamosus_ and _T. gigas_ were rare or, as in the latter case, not present at all. Such anomalies in the distribution of such common species which occur so abundantly both north and south of Arno Atoll are inexplicable at present. Thus, one of the significant differences between natives of the Northern and Southern Marshalls is the great dependence upon these clams in the north and the almost total disregard of them in the south.

Spiny lobsters (_Panulirus penicillatus_ and _P. japonicus_) are present in considerable quantity on both the seaward and lagoon reefs. Frequent fishing trips are made, usually at night with a torch, to secure these lobsters. Many young lobsters were observed in small holes in coral heads.

Perhaps the most frequently sought marine invertebrate is the "leked" (_Canarum luhuanum luhuanum_) a gastropod belonging to the family Strombidae. These occur on the lagoon reefs by the thousands, and at each low neap tide the women and children flock onto the reef to collect them. In spite of what appears to be one of the most intensive of all the native fisheries, these gastropods seem to withstand the fishing mortality.

Plant resources

Like most coral reefs, the algae is sparse except for the Lithothamnium at the windward reef edges. Toward shore on the wide windward lagoon reefs algae grows more abundantly than elsewhere. The Arnoese make absolutely no use of the algae as either food or fertilizer.

General Impressions

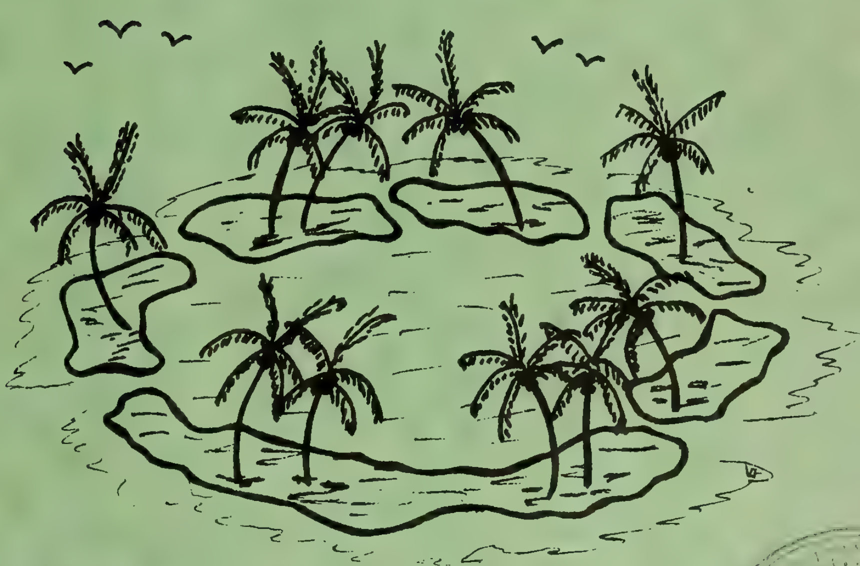
The reefs and lagoon of Arno Atoll are exceedingly productive of organisms. In general the fauna and flora resembles other coral atolls of the Central Pacific, but certain differences are striking. While the author believes that studies on one atoll may serve as a sound basis for regulations on and interpretations of others, it is certainly obvious that real and important differences do exist. Causes of such differences are not readily apparent, but detailed studies on ocean currents, upwelling, and life histories of organisms will shed much light on variations in species and population densities and overall productivity. In selecting sites for future programs of investigation it would be well to choose areas in different oceanic environments so that they may be compared with previous studies in regions of different environmental conditions. Such comparisons may enable one to associate variations with known environmental differences. Once these differences were related to environmental changes, generalizations for all atolls within certain defined environmental conditions could be made.

The marine environment at Arno is of great importance to the people but it is underutilized by the present population. This is a significant fact because Arno is considered to be a heavily populated atoll. Should the present level of population be the result of natural forces rather than that imposed by unnatural phenomena, viz., birth control, disease, emigration, etc., it is not the supply of marine resources which exerts the regulatory effect.

Nos. 5, 6, 7 November 15, 1951

ATOLL RESEARCH BULLETIN

5. *The Soils of Arno Atoll, Marshall Islands.*
6. *The Agriculture of Arno Atoll, Marshall Islands.*
7. *The Plants of Arno Atoll, Marshall Islands*



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ATOLL RESEARCH BULLETIN

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Washington, D. C.

November 15, 1951

ACKNOWLEDGEMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board, including the launching of the Atoll Research Bulletin.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs, CIMA, SIM, and ICCP, during the past five years. The Coral Atoll Program is a part of SIM.

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ATOLL RESEARCH BULLETIN

5. The Soils of Arno Atoll, Marshall Islands

Issued by

PACIFIC SCIENCE BOARD

National Research Council

Washington, D. C.

November 15, 1951

THE SOILS OF ARNO ATOLL, MARSHALL ISLANDS

SCIENTIFIC INVESTIGATIONS IN MICRONESIA

Pacific Science Board

National Research Council

Earl L. Stone, Jr.
Cornell University
Ithaca, New York
February 1951

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The writer participated in the 1950 SIM (Scientific Investigations in Micronesia) Project of the Pacific Science Board and the following report covers field work for the period 13 June - 5 August 1950. This project is supported by funds granted to the National Academy of Sciences by the Office of Naval Research, and the field work was carried out with the active assistance of the Navy Department, the Military Air Transport Service, and the officials of the Civil Administrative Staff of the Trust Territory (Navy).

Members of the Civil Administrative Staff at Kwajalein and Majuro were exceedingly helpful in many ways. The assistance of Miss Ernestine Akers, Honolulu secretary of the Pacific Science Board, greatly facilitated arrangements during our brief stop over there.

I am indebted to Dr. John W. Wells for an introduction to atoll geomorphology and for many stimulating conversations during the preparation of this report.

INTRODUCTION

In preparing this field report I have had in mind the meager knowledge of atoll soils presently available and a realization that subsequent reports to technical journals are much more likely to be found and comprehended by soil scientists than by the laity. Therefore, the first section has been given over to a generalized discussion of soil formation on unraised atolls. The second section, the field report proper, is an account of the summer's work on the soils of Arno.

Part II, Agriculture of Arno Atoll, has already been prepared and because of this slightly illogical sequence a certain amount of overlapping and some minor discrepancies may be found in comparing the separate reports.

> "The soil is fairly productive. Its larger islands are covered with grass, fine groves of coconuts, with magnificent breadfruit, Pandanus and Pisonia, and the usual belt of low growing vegetation growing upon the summit of the beach" -- Alexander Agassiz, of Arno Atoll in 1900.

C O N T E N T S

G E N E R A L

Land Formation and Destruction

Soil Formation

S O I L S O F A R N O

GENERAL

Land Formation and Destruction

FORMATION

Land formation can be viewed as the culminating process in atoll development or as a minor consequence, a superficial collection of fragments that happens to protrude above sea level. In terms of mass the land is but an insignificant fraction of the atoll and occupies only a small part of the area. In discussing the soils of the atoll we unavoidably incline to the view that land formation is the culminating process but we will treat it here only to the extent necessary for an understanding of the soils.

There is no evidence that the present atoll surface has been uplifted. (See report of the Geologist.) For our purposes we will assume that the land has formed on a platform of consolidated material having an elevation at or slightly below mean low tide. Ordinarily this platform will be consolidated reef rock but occasionally it may be cemented sandstone or "conglomerate". The nature of this platform can be seen on the typhoon swept areas where land formerly existed and in exposures in the interior of Tinak, L'angar and Bikareij Islands. Although doubtless permeable to some degree this platform is considered much less so than the materials subsequently deposited upon it. On Arno there is no evidence that land has formed over unconsolidated materials and this possibility will not be considered further here.

Even the most cursory examination of the wider islands reveals that two major classes of materials have entered into their composition. Over the greater part of the atoll the seaward side of the land is composed largely or entirely of rock torn from the reef. Often these fragments have been rounded by wave action before deposition but again the pieces may have more or less of

their original jagged contour. Most of the rocky land appears to have been formed by the progressive outward building of a rampart composed of these coarse materials thrown up by storms. The younger age of the seaward side of this land is generally recognized and in fact rampart formation is in progress along much of the coast. Since it owes its formation to storms the surface of the rampart tends to mark the highest level to which the largest waves can carry coarse material. Thus this level is higher on the more exposed coasts subject to frequent storms, such as on L'angar Island, and it is lower elsewhere. Occasional great storms such as accompany typhoons may heap rock well beyond the edge of the rampart, even burying inland surfaces. In either case, included with the rock is a greater or lesser amount of sand and gravel ground from the rocks. Usually the stony land slopes downward slightly away from the coast, possibly because of weathering of the older materials.

It is not possible to say with certainty that the rampart is always the first formed land but in most cases it is difficult to postulate otherwise. Protected by the rampart, the quieter waters of the lagoon pile sand against it and the resulting sandy shelf often widens more rapidly than the outbuilding rampart. This process is particularly effective where the reef and hence the rampart, forms a sharp concavity. As is generally true along coasts, such embayments are more readily filled by wave-worn sediments and are protected from along-shore currents. The progressive widening of Arno Island, although now slow, is known to the people there because inland and parallel with the beach they find rows of pumice pebbles such as occur along the present beach.

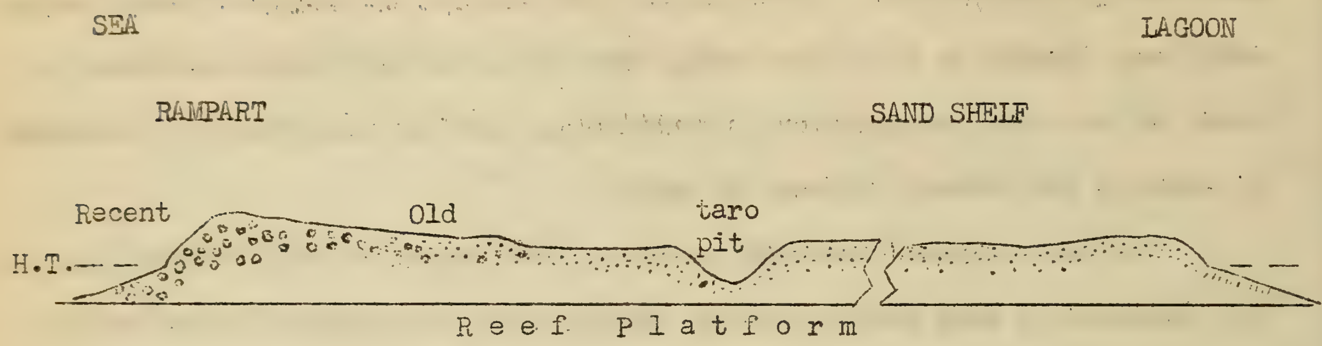
Beach sands are not limited to the lagoon side of the land, although much more common there. On the seaward side the occurrence is most probable on lee coasts and again in embayments concave towards the sea. The narrow land just northwest of Ine village has a sandy seaward beach and in places the

soils immediately back of the beach show signs of having been veneered with sand during storm periods. Although at first thought the height of sandy lands would seem limited to high tide level, wave action during storms continues to throw up sands and accumulation is doubtlessly aided by the effect of vegetation in reducing the outward drainage of waters.

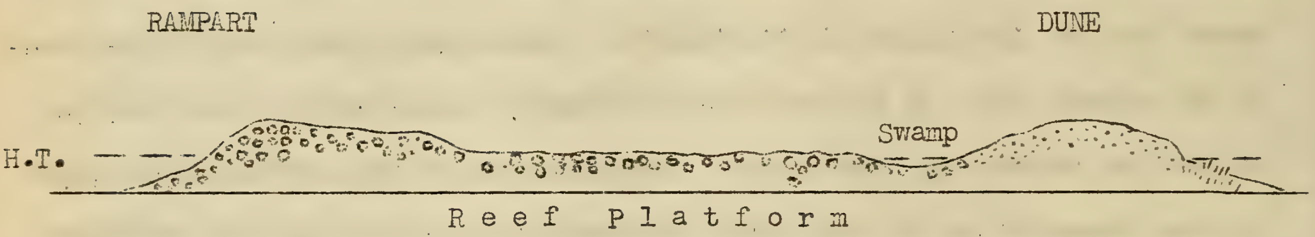
The major element involved in raising the height of land, however, is the formation of sand dunes which are common along the windward lagoon shores. Dune formation proceeds most rapidly where a sandy beach is uncovered at low tide and exposed to the northeast trades. On Arno the maximum dune height observed was perhaps twelve feet above high tide though much higher dunes are known on other low islands in the Pacific. Occasionally small dune areas occur on the seaward side, as at one point on Bikareij Island where a small section of the low rampart has been buried. When supplies of sand are ample the speed of dune formation may be very rapid as exemplified by the high dune northwest of the wide part of Jab'u formed and vegetated since the typhoon of 1918.

The three processes involved in building a rampart, sand shelf and lagoon dune may combine to give a land high on both shores and lower in the center. Such an orderly process of formation is far from common, as the cross-sections and soil maps reveal. Even apart from catastrophies, the vagaries of wind and storm bring cycles of addition and removal, often transferring materials from one point to another nearby. Dunes are often cut away or sometimes left inland when a new cycle of beach building takes place. Unfilled areas may be cut off from the sea by ramparts or dune ridges, giving rise to swamps or wet soils. A single minor storm may sweep away the accumulation of months or, again, heap fine materials on coarse or coarse on fine. The cross-sections of Figure I are diagrammatic sketches of conditions actually found. It may be emphasized that nearby all of the inland basins and low interiors of the islands of Arno are obviously structural; they have been formed in the course of island building, or rebuilding, rather than by solution.

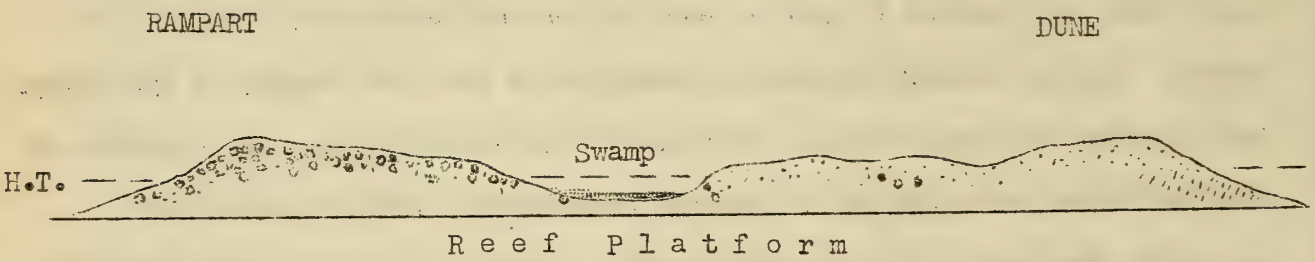
Fig. 1. DIAGRAMMATIC CROSS SECTIONS OF SOME ISLAND TYPES



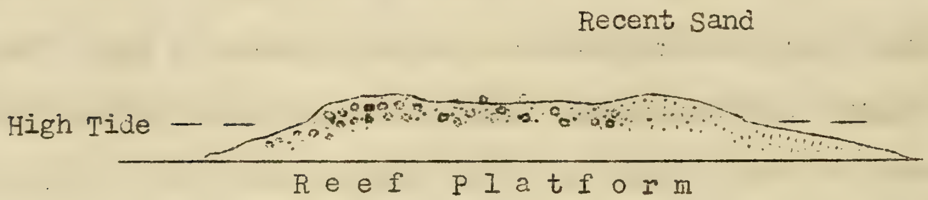
(a) Wide sandy island.



(b) Island with low stony interior.



(c) Island with enclosed basin.



(d) Narrow island.

Although the developing land is subject to the sea there are stabilizing influences that tend to protect its integrity. The slow outward and upward growth of the reef gradually reduces the violence of the waves which beat upon the land. Ramparts and dunes shelter the interior from all but the largest storms and as the land widens there is less likelihood that storm waves can sweep across it. Moreover, the shore itself comes to be underlain with a sandstone or conglomerate formed as outward flowing waters saturated with calcium bicarbonate cement the beach materials. The beach sandstone or conglomerate offers no absolute protection as many offshore blocks of these clearly show, but rapid formation helps to defend additions made to existing lands. The ground water may bring about cementation elsewhere than on the beaches and locally phosphatic cementation may stabilize loose materials. 1/

The stabilizing effects of vegetation are obvious. The root mat binds the surface soil and the tops of plants both large and small reduce the violence of surface flow by wind and water, decreasing erosion and encouraging deposition. The stabilization is probably important in protecting ramparts and dunes but it is easy to overestimate the importance of vegetation; land also forms on dry atolls where the vegetation today is too sparse and small to have major effects.

DESTRUCTION

Despite the stabilizing influences above, the narrower lands cannot be made secure against destruction by major storms; in fact, on a geological time scale such lands may have a somewhat ephemeral existence. Typhoons are considered relatively rare in the southern Marshalls but are well known. Those of 1905 and 1918 have been well documented by the Germans and Japanese then resident. Lijömmar, an old man of Ine village, recalls four typhoons in his lifetime, including the above two, and knew of another in the days of his grandparents. For each of the four he described the windshifts and an intermediate

1/ Current hypothese of beach rock formation seem to rule out the simple assumptions made here.

period of calm that indicate the passage of a typhoon center. Thus, it seems that typhoons and their attendant effects must be considered normal in the sequence of land formation.

On Arno the typhoon of 1905 was clearly the most destructive in a period of perhaps a century. Along the entire east coast of the atoll there was the long island of Namej (the Terranova of Agassiz), an unbroken land from the pass near the east end of Ine Island to the tip of present day L'angar Island. When the storm ended the wider portions of this island lay as isolated fragments, their centers intact. Much of the narrow land had been washed over by the great waves that cut away the land margins and replaced the former surface with primitive rock and sand. Other land had disappeared entirely, leaving the reef platform bare, perhaps as much as it had been before the land formed. In the subsequent 45 years this area has rebuilt to a considerable degree, with sand spits linking the individual islands and a rampart again manteling part of the bare platform. The same typhoon is said to have caused extensive damage on Ine Island; the narrow land between Ine Village and Jab'u was reduced in width and the effects are plainly visible in the condition of the narrower parts of the island from Jab'u west to Lukwöj.

The 1918 typhoon was less destructive but left some effects. The small island of Enen'ëdrik is said to have been separated from the southern end of Arno Island by this storm. The narrow land northwest of Jab'u was reputedly washed over for the second time by this typhoon and, at a point where the seaward reef is indented, the land was again trenched through to the reef rock below. Here is demonstrated one way in which typhoones destroy the land surface: The waves coming across the land from the seaward side began undercutting at the lagoon shore; the dense root mat of coconuts presumably held the surface layers but the sand below was readily washed away and thus a

shallow "waterfall" retreated across the island. For the most part this waterfall cut only about half way across the island and remains as a deeply scalloped escarpment, 3 to 4 feet high. The individual "scallops" are the "washout pits" that can be recognized elsewhere on Ine Island.

This area, like Namej, indicates rapidity of rebuilding; the channel has vanished entirely although its surface and that below the escarpment are lower than the former land. Along the lagoon shore a high dune has been built and now supports a young coconut grove.

GROUNDWATER

The groundwater is discussed in detail in the report of the Hydrologist and it is sufficient here to mention its existence. The classical Ghyben-Herzberg theory would picture a lens of fresh water floating in and on the salt water, both within a matrix of unconsolidated coral detritus that prevents turbulent mixing. It is evident that this view must be altered somewhat if we consider that the fresh water overlies a more or less impermeable platform beneath. The salinity of the groundwater is influenced by rainfall, of course, and so is subject to possible seasonal changes. Other obvious factors are distance from the shore and subsurface permeability, and the latter, in turn, is affected by the relative coarseness of the materials composing the land.

The hydrological investigations on Arno by D. C. Cox (Atoll Research Bulletin 8) indicate that the reef platform must have an appreciable permeability and that a well developed Ghyben-Herzberg lens is present.

Soil Formation

There are many different rainfall regimes throughout the Pacific and in consequence there are "wet" islands and "dry" islands, as well as others subject to periodicities of rainfall, either annual or at irregular intervals. It is quite obvious that moisture influences vegetation and leaching processes. In addition, the intensity and distribution of dry periods regulates soil salinity and the possible concentration or precipitation of dissolved substances. Thus it should be kept in mind that in the following we are principally concerned with a "wet" atoll having an annual precipitation of some 120 inches with a short and only "relatively dry" season.

Throughout the world there are areas of limestone resembling the atolls in chemical composition but uplifted for various periods. The soils developed on these indicate the course through which the atoll soils would pass if they remained above the sea for sufficient time. In the oldest such areas the calcium and magnesium carbonates, which make up such a large part of the present atolls, have been entirely dissolved from the surface layers and often from a considerable depth; the soil then consists of combinations of aluminum, silica, iron and other constituents originally present as only small percentages. The time required for such formation is great and the solution of several feet of limestone may yield only an inch or two of soil. In contrast the present atoll soils are extremely youthful and are classified as <u>lithosols</u> and <u>regosols</u>. /1. The surface layers have been darkened by addition of organic matter and there has been some solution of carbonates but in the main the materials of the soils have been little altered.

/1 <u>Lithosols</u> "An azonal group of soils with little or no horizon differentation ... if deeper, consisting largely of rocks and stones"

<u>Regosols</u> "An azonal group of soils with little or no horizon differentation, deep ... over bedrock, and generaly non-stony, consisting of materials such as loess, marine and lacustrine sediments and sands."

PHYSICAL AND CHEMICAL NATURE OF THE PARENT MATERIALS

It has been mentioned that much of the sea-derived material is coarse but mixed with this is a varying proportion of fine gravel and sand. /2 Here and there are beaches made up entirely of the finer materials. Many of the cobbles and jagged fragments are made up of somewhat porous corals which hold appreciable amounts of moisture and are penetrated by roots to some extent; thus they are more favorable for plant growth and rather more susceptible to disintegration than size alone would suggest.

The beach deposits formed along the lagoon shores vary in particle size from medium to very coarse sands, often with an admixture of fine gravel; locally they may consist of gravelly sands. The dune sands are finer and relatively uniform in size but mixtures occur when dune sands are reworked or washed over adjacent land. Soils formed from "coral mud" were not found at Arno but have been reported elsewhere.

The coarse materials are very largely composed of stony corals and Lithothamnion rock, whereas the lagoon sands contain a high proportion of Foraminifera tests and Halimeda fragments, as well as ground up coral and shells. Several investigators of "coral" reefs have pointed out that calcareous algae and other organisms often contribute more material to the reefs than the corals themselves; thus Mayor suggested that Rose Atoll was properly a "Lithothamnion atoll".

These distinctions become more significant when the results of chemical analyses of various organisms are compared (Table I). The inorganic parts of the reef building corals consist almost entirely of calcium carbonate, whereas some of the Lithothamnion group contain as high as 25% magnesium carbonate.

/2 The U. S. Soil Survey classification delimits particle sizes as follows: stones (irregular) and cobbles (rounded), 10"-3"; coarse gravel, 3"-1/2"; fine gravel 1/2"-2 mm.; very coarse sand 2 mm.-1 mm.; coarse sand, 1mm.-0.2mm.

Another alga, Halimeda, however, contains only about 1% or less of magnesium carbonate. Moreover, the two minerals species of calcium carbonate, calcite and aragonite, which differ somewhat in solubility, are characteristic of different organisms. Some organisms that contribute little mass to the reef are nevertheless sources of certain elements, such as phosphorus, needed for plant growth.

Table I <u>Range in Inorganic Composition of Some Marine Invertebrates</u>
After Clark and Wheeler (U. S. Geol. Surv. Prof. Paper 124, 1924) and Twenhofel (Principles of Sedimentation, 1939).

	$CaCO_3$ %	$MgCO_3$ %	SiO_2 %	$Ca_3P_2O_5$ %	$(AlFe)_2O_3$ %	$CaSO_4$ %
Alcyonarian corals	73-99	.35-15.7	0.4-1.7	Tr-8.6	Tr-1.0	Tr - 5.4
Madreporian corals	98-99+	.09-1.1	0-1.2	0-Tr	0-0.7	0 - .2
Foraminifera	77-90	1.8-11.0	Tr-15	Tr	Tr-5.0	0
Echinoderms	78-93	5.0-15.0	0-10.0	Tr-1.9	0.1-5.2	Tr - 4.2
Mollusks	94-99.9	0-6.0	0-2.2	0-0.9	0.4-1.9	0 - 0.2
Crustaceans	29-83	3.7-16.0	0-3.8	8.7-27.0	.06-8.9	Tr - 5.3
Calcareous algae	74-99	.02-25.0	.02-2.1	Tr-0.4	.01 to 1.6	.03 to 1.4

Soils formed by weathering of consolidated limestones are not common on Arno and presumably this is likewise true of other atolls that have not been uplifted, since the primary zone of cementation is near tide level. The composition of cemented limesands and conglomerates resembles that of the unconsolidated materials but the former are obviously less suitable for soil and plant development. Such rock is usually permeable to some degree and roots and percolating waters soon develop numerous deep fissures and pockets of soil material.

Brown phosphate rock occurs on many low islands; this is formed by phosphate leaching from guano deposits into limy materials beneath and there forming insoluble calcium phosphates. The calcium carbonate is replaced wholly or in part by the phosphate and thus (excepting peat accumulations) acid soils, if found at all, occur on phosphate areas, e.g. Holei Islet, Palmyra Island, as reported by Christophersen (Bishop Mus. Bul. 44, 1947). During the replacement process the material is usually cemented if not already so, hence imposing the same mechanical limitations to plant growth mentioned above. The three small areas of phosphate rock observed on Arno, however, were highly fissured and contained pockets of unconsolidated sand.

Wave drifted pumice has been found on many low islands and locally its mass may be great enough to affect the soil or plant growth (c.f. the Funifuti report). On Arno, except to provide whetstones for the natives, its significance is probably nil; even where it appears most abundant its weight per unit land area is negligible. Low islands near volcanic areas may benefit from ash deposits but Arno is remote from these.

By the nature of atoll formation other rocks and minerals would not be expected, except for those transported by man or a rare erratic drafted ashore enclosed in tree roots. This expectation is not always a safe one: The sweeping conclusions concerning soil development drawn by Lipman and Shelley (Carnegie Inst. Publ. 340:201-208, 1924) from analyses of a single set of samples from Rose Atoll are entirely vitiated by the discovery of basalt fragments in the reef. Basalt had been reported by the Wilkes Expedition and by Couthovy long before, but these reports were considered erroneous by Mayor (Carnegie Inst. Publ. 340:73-79, 1924) who collected the material analysed. Subsequent collection by L. P. Shultz (Personal communication) has verified the presence of basalt. Likewise David and Sweet (The Atoll of Funafuti, Sect. V,

1904) present a soil analysis but note that a little of the soil from the sample locality had been brought in as ballast from Samoa.

PHYSICAL FACTORS

Once exposed above the sea the land materials are subject to the continuous action of atmospheric and biological agents. The first rains dilute and then rinse out the salt left by the depositing waves. On wet atolls this is repeated when salt is again added by storm waves, spray or evaporating brackish waters whereas on dry atolls the rainfall may be insufficient to remove the salt from the surface layers. Other substances, calcium and magnesium carbonates and the small percentages of other elements that occur with them or in the dead organic materials, are much more slowly dissolved by rainwater.

Solution

Nevertheless solution is the dominant physical process acting upon the land. The carbonic acid released by roots and organic matter decomposition or carried into the soil by rainfall converts calcium carbonate to the soluble bicarbonate which then moves into the groundwater. Some of this precipitates along the shores, cementing sand and rubble to beachrock, but it is lost from the island interiors. We may calculate [13] that carbon dioxide dissolved in rainfall before it reaches the soil is alone sufficient to reduce the land level about 1 cm. per century. This rate may be increased by a few to several-fold by the effects of living organisms and their decomposition products. The estimates of Sayles (Proc. Am. Acad. Arts and Sci. 66:380-467, 1931) on the weathering of consolidated windblown limesand in Bermuda indicated reduction of the land surface at the rate of 6.1 cm. per 100 years. This is little or nothing in one man's span but in a geological sense the process is rapid. Thus

[13] 120" rainfall per year, solubility of calcium .52 millimols/liter at 25°C and .0031 atm. CO_2, assumed density of the sand 1.8.

it appears that as an island widens with time so does its interior lower and a few millenia of such weathering would bring its surface to the level of the water table. There is no evidence that this has taken place on Arno atoll but the consideration again demonstrates the youthful condition of the land surface.

Solution progresses rapidly in the upper layers. The innermost margins of the belt of stony land are much less coarse than the outer beach for as they weather the large fragments give rise to smaller. The gravel-sized particles found within the upper organic horizon of the older soils are often soft and easily crushed, and frequently are penetrated by roots. Similarly, the sand particles are most disintegrated within this zone. On Arno the most highly weathered soils often contain much more gravel in the surface horizon than immediately below. Although other explanations are possible, the general concurrence of this suggests concentration of the gravel by solution of the finer particles.

Cementation

Except for beachrock formation, cementation by precipitation of dissolved carbonates in the upper few feet of soil is not of consequence under Arno conditions. Occasionally slight cementation of sand particles in the immediate vicinity of decaying roots was observed and in one instance slight cementation was noted throughout the sand overlying a buried organic layer near the groundwater level. There are, however, no "hardpans" or illuvial horizons within the soil proper on Arno nor would there be expected under the prevailing conditions of rainfall and parent material.

In a few profiles examined lagoon laid sands rested conformably on unweathered strongly cemented sandstone at a depth of 40" or more; likewise several wells penetrated to sandstone. In no case were these layers uncovered sufficiently to determine whether they lacked the slope characteristic of beach-

rock and hence it is uncertain whether they originated at the time of land formation or later. Near the boundary between Lukwög and Kinajöng on Ine Island is a soft, relatively fine textured sandstone well above high tide level. This is thought to have formed in the lower part of a dune and subsequently been exposed by storm action.

In a sense cementation is merely an incidental consequence of secondary lime deposition and can be expected wherever water saturated with calcium bicarbonate evaporates or loses carbon dioxide, as by warming or escape of excess acquired under the higher carbon dioxide pressure in the upper soil.

In regions of scanty rainfall or frequent alternation of wet and dry periods cementation near the soil surface is possible and may account for the "hardpan" observed in the soils of Christmas and Fanning Islands by Christophersen. Baas Becking's ("The Soils of Coral Atolls", Preliminary Notes on Project E-6, South Pacific Comm., 1950) interpretation of such hardpan, however, suffers from some misapprehension as to the processes involved. One common mode of formation (e.g. the caliche of subhumid soils of the western United States) is through limited penetration of the scanty rainfall, the periods of wetting being followed by drying which causes precipitation of carbonates. Under particular climatic conditions such "hardpans" may be normal but their occurrence elsewhere ought not to be assumed.

Cementations by phosphates leached from guano deposits has been mentioned in the previous section.

Considerable care is necessary to distinguish between "hardpan" or indurated layers formed in the normal course of soil development and somewhat similar layers that originated otherwise and later, by exposure or burial, came to occur beneath a shallow soil horizon. For example, on Palmyra Island Christophersen described a profile with 10 cm. of "mold" overlying a 10 cm.

thickness of phosphatic "hardpan" which in turn rested on coral sands; almost certainly this is more truly seen as a shallow, highly organic soil layer developing on a thin bed of phosphatic rock. The rock, rather than the sand below, is the parent material of the soil and antedates it. Similar soils are found on Arno over deeper beds of phosphate rock which can in no sense be regarded as "hardpan".

Soil Movement and Burial

Likewise, burial of an existing soil, as by the debris thrown up in great storms, followed by soil development on the new material can give rise to an anomolous profile. Such a buried soil with a black horizon at the surface and a second dark horizon at some depth was found on Ine Island (Profile #4). A somewhat similar profile was described, although apparently not recognized as such, on Palmyra Island by Christophersen. Two profiles on Ile aux Canards described by Baas-Becking are almost certainly due to burial of a pre-existing soil, though he curiously regarded the dark layers at depth as illuvial horizons. Unpublished descriptions, photographs and analytical data from profiles taken on Canton Island by Dr. L. H. MacDaniels indicate that two of these have buried organic horizons.

In addition to burial of well developed soils small periodic additions of wind-blow or wave-flung sand on a vegetated area may result in a very considerable depth of "surface" soil colored by organic residues.

The importance of dune formations in raising land height has been referred to previously. Apparently there is little movement of sand inland beyond the dune under the usual Arno conditions where dunes are soon vegetated, thus increasing their effectiveness in trapping sand. Since windbreaks diminish wind velocities for some little distance to windward, as well as to leeward, it may be that tall vegetation, such as the palms, limits dune height.

Despite their texture, newly formed or sparsely vegetated dunes are subject to considerable slope washing during heavy rains. The sand eroded from the steeper slopes is deposited as the water sinks into the soil (Profile #27) and in fact effects a marked flattening of the inland dune slope. This process is intensified by clearing and burning in the coconut groves but the mixture of beach and dune sands found in stabilized soils near older dunes suggests that it has been of general occurrence. It is probable that rapid washing of sand excavated from the taro pits brought about the very gentle slopes of their surrounding rims.

Apart from slope washing, soil movement inland is of negligible proportions except near village areas where rain is concentrated in the hard-packed walks. The resulting accumulation of sand in low places nearby is of no consequence in soil development but numerous sand pits dug to resurface the walks provide excellent profile exposures.

Shore Erosion and Storm Damage

In addition to the drastic typhoon damage already mentioned, there may well be additional effects no longer obvious, such as saturation of organic exchange complex with sodium, etc. Unusual storms or a cycle of shore erosion may cut away the land to such an extent that soils of the interior are exposed along the beach and ultimately modified by the attendant changes in vegetation and environment. In consequence of typhoons and cycles of cutting and deposition, irregular patterns of micro-relief and soil distribution and occasional profile anomalies must be considered "normal".

BIOLOGICAL FACTORS

Organic Matter

From previous paragraphs it is already apparent that living vegetation and its disintegrating products contribute greatly to the solution of calcium

carbonate by their production of carbonic acid. Through penetration of roots this process may occur slowly even well within large pieces of porous coral. Baas-Becking has called attention to the abundance of algae which on Arno, as elsewhere on the moist tropics, mantle the surface of rocks and even the sand in open groves.

Apart from the effects on solubility the organic matter itself is of great significance in soil formation. In the absence of the more profound changes that mark mature soils, the presence of organic matter is the principal feature characterizing the atoll soil. It is obviously the principal source of cation exchange capacity. Further, the accumulation of nitrogen parallels that of well decomposed organic matter ("humus") for there is a fixed carbon-nitrogen ratio of approximately 10 or 12 to 1.

The breakdown of organic remains is carried on in large part by micro-organisms but earthworms are often abundant, and small snails locally so, in the darker soils.[/4] The earthworms are presumably significant agents in mixing the surface matter with mineral soil although root growth and decay provides another means of incorporation. Dead woody tissues are generally broken down by termites. In localized areas burrowing crabs accomplish very considerable mixing. Where excessive moisture prevents normal oxidation of organic materials these accumulate giving rise to peats and mucks, the distinction being the higher inorganic content of the muck.

<u>Nitrogen Fixation</u>

Baas-Becking has stressed the possible role of algae as nitrogen fixer and from soil samples collected by him a new group of nitrogen bacteria, Beijerinckia, has been isolated by Derx. Azotobacter has not been reported in atoll soils but would be expected in this habitat.

/4 Collections of these were made by Dr. LaRivers.

On Arno legumes are common and nodules were observed on *Vigna marina*, *Sophora tomentosa* and *Canavalia sericea*. On the latter they occur on the smaller roots at some distance from the root crown and hence they may be easily missed. The Vigna seems particularly important for it forms thick masses in the open groves and extends aggressively onto sand beaches, old dwelling sites and burned areas. The two species of Canavalia, though less abundant, are vigorous vines in lightly shaded areas. *Intsia bijuga* is the only leguminous tree but its abundance in the original forest cannot be estimated accurately now.

Seabirds

Throughout the dry islands of the Pacific nesting seabirds have created guano deposits and highly nitrogenous soils. Under wet conditions such accumulations do not remain long but the numerous areas of phosphate rock are generally considered to have originated beneath such guano areas. As mentioned, the phosphate was precipitated as the insoluble calcium salt when carried into the calcareous material beneath, whereas the soluble nitrates were washed away. The resulting product is usually well cemented although unconsolidated brown sands may occur with the rock. Phosphate rock, guano, and soils strongly influenced by guano occur only where large numbers of seabirds congregated for long periods. Even away from these areas, however, the birds must have a very considerable effect on the soil. They are common in small numbers on many islands where they roost and nest (see report of the Zoologist); feeding along the beaches and at sea they are the only significant agents adding to the land from the fertility of the sea.

Man

Native man himself is a biological agent although the activities of the island inhabitants a century ago were more localized than now. Many of the soils that originated in dense native forests now support open coconut groves; it is

evident that such changes must profoundly alter soil properties but the extent of this cannot be well estimated. The taro pits are an obvious disturbance and the area influenced can be approximated grossly, but there is no way to recognize areas influenced by old house sites and fires.

Man also has an effect on the fertility levels of the soil which in the Marshalls, at least, is curiously counter to that of the seabirds. As the anthropologists have noted, the Marshallese went to the tidal beach or reef to defecate. This custom, however commendable as a sanitary measure, has meant continuing loss from the land of most of the nutrient elements contained in the diet. In Holland the soils about dwelling sites occupied for centuries have in some cases been colored by iron phosphates which accumulated through a concentration of phosphorus from the surrounding areas cropped by man and his domestic animals. It seems probably that the reverse has been occurring in various sections of Arno and its possible importance is greater because of the very limited land area occupied and the relatively dense population.

A recent source of nutrient losses is through the export of copra; for example, each ton carries away the phosphorus equivalent of 25 pounds or more of superphosphate.

SOILS OF ARNO

The soils of Arno atoll have developed under a uniform temperature of about 81° F. and a rainfall approximating 120 inches per year, rather well distributed except for a drier period that usually occurs from January to March. As mentioned, the well drained soils are regosols and lithosols and even those called "well developed" are relatively primitive. In terms of profile nomenclature they are "A-C soils" with an A_1 horizon (zone of incorporated organic matter) and, usually, a narrow A_3 (transitional) horizon passing directly into the relatively unaltered parent material, the C horizon. As a group these soils are a tropical equivalent of the "humus-carbonate soils" of the European workers.

The soils of Arno were classified into series and types on the basis of common properties, particularly those relating to profile morphology. Complexes are recurring associations of various soil and land types that cannot be readily described or mapped as separate units.

TYPES AND MORPHOLOGY

A. Soils developed on sands and gravelly sands.

1. Shioya loamy sand: This unit was first described on Okinawa and subsequently has been mapped on Saipan and several islands of the Pacific. It is a well drained alkaline soil formed principally on lagoon laid sands. The profile consists of a surface horizon 5 to 8 inches deep darkened by organic matter to a light gray, gray, or brownish gray color, resting on light-colored limesands. It is typical of the younger but not recent lands and is widespread particularly along windward lagoon coasts and on narrow lands; it is usually absent from the seaward coasts and wider island interiors.

A characteristic profile is as follows:

0 - 7" Friable loamy sand, dark gray (10 YR 4/1) /5 in color when moist, single-grained or weakly aggregated. pH 7.8

7 - 8" Transitional.

8 - 40"+ Single-grained pinkish white (7.5 YR 9/2) loamy sand composed of forams and ground shells, coral and Halimeda fragments. pH 8.4

On wider islands there is often a transitional zone between this unit and the Arno loamy sand inland. As mapped, the unit contains some areas of the Shioya sand, particularly along aggrading coasts.

The present vegetation of this unit is usually open coconut grove although small areas are in the mixed scrub forest (see Part II). Scaevola, Messerschmidia (Tournefortia), Morinda and Guettarda often form a dense undergrowth in poorly maintained groves. The ground cover depends to some extent on the degree of shading and presumably on salinity although this was not checked in the field. Wedelia, Fimbristylis, Vigna, Triumfetta, Tacca, Centella and the grasses, Thuarea, Eleusine, Lepturus and _Paspalum vaginatum_ are often common in open groves. Under present conditions coconuts are certainly the most suitable crop for this land.

The groundwater underlying this soil may be fresh or brackish but it is doubtful whether the surface soils are normally ever very salty. Exposure and groundwater salinity affect the vegetation and hence, together with age, determine the relative development of the soils within this type. Under favorable conditions their development is fairly rapid; some areas swept by the 1905 typhoon and subsequently well vegetated were mapped as belonging to this unit, although recognizably younger than the modal profile.

Christophersen's descriptions, "sand of a lightish gray brown" on Washington Island, the "grayish brown soil" of the coconut plantations on

/5 The color names and the notations for hue, value and chroma are according to the Munsell system. Unless otherwise noted, they apply to dry samples.

Fanning Island and "lightish gray brown coral sand...mixed with root fibers, but still with a low percentage of organic matter." on the beach crests of Palmyra Island appear to place these soils with either this unit or the Shioya sand later described.

2. Shioya gravelly loamy sand: This type differs from the preceding chiefly in its content of gravel-sized fragments which may be of either lagoon or sea reef origin. Small areas of stony loamy sands are included. Most of the unit occurs on the narrow islands and part of it shows evidence of old typhoon damage.

The profile is similar to that of the loamy sand although sometimes more irregular because of the coarse materials. The vegetation is largely open coconut grove with vigorous invasion of Scaevola and Messerschmidia from the shoreline when clearing is neglected.

3. Shioya sand: The Shioya sand differs from the loamy sand in its lighter colored and generally shallower zone of organic incorporation; the textural distinction does not always exist. As recognized in the field this type includes dune sands, and medium and coarse beach sands, all of recent origin. Small areas of gravelly sand were not separated nor could a salty phase be recognized with certainty in the field.

The largest areas of this unit are recently vegetated swept lands and sands formed after the 1905 and 1918 typhoons. A belt of this type is commonly found between the sandy beaches and the Shioya loamy sand inland but is often too narrow to map.

A typical profile of the Shioya sand follows:

0 - 3 - 6" Single-grained pinkish gray (75 YR 6/2-7/2) (moist) sand or loamy sand, recognizably a mixture of decomposing organic matter, brown roots and white sand. pH 8.2. Changing abruptly through a narrow transitional zone to:

3 - 6 -30"+ White or pinkish white (75 YR 9/1 - 9/2) limesand.

Areas of Shioya sand adjacent to the loamy sand usually have been planted to coconuts; elsewhere the characteristic vegetation consists of Scaevola and Messerschmidia, occasionally with Pemphis or Suriana, along the coast, and a mixture of young trees, such as Calophyllum, Guettarda, Terminalia Morinda and Pandanus. Triumfetta, Fimbristylis and the grasses Thuarea, Eleusine, and Lepturus, and Vigna are characteristic ground cover plants.

In the main this type is regarded as a juvenile stage of the Shioya loamy sand. Its development varies with that of the vegetation it supports which, in turn, is restricted by salinity and lack of fertility. Development is most rapid when the soil adjoins older land and shares its outflowing groundwater, leaf litter and seed supply.

4. <u>Arno loamy sand</u> (tentative series): This is the well-drained, dark-colored calcareous soil formed on old beach and dune sands under the vegetation of the wider island interiors. This soil differs from the Shioya loamy sand in the dark color and very high organic matter content of the surface horizon (Table II). It is literally a black-and-white soil, with extreme contrast between the well defined surface horizon and the light colored limesands beneath. This unit occurs in the interiors of Arno, Tinak, Kilange, Bikareij and the several wider sections of Ine Island.

A representative profile is #25 from Arno Island:

Surface	Scattered twigs and breadfruit leaves.
0 - 11"	Highly organic, granular loamy sand or sandy loam, somewhat plastic when worked. Black when moist, very dark gray (10 YR 3/1) when dry, heavily flecked with lighter sand particles. pH 7.5. Earthworms abundant.
11 - 13"	Abrupt transition from above to
13 - 21"	Single grained, light gray loamy sand stained with organic matter becoming white (10 YR 8/2) at a depth of a few inches. pH 8.4.
21 - 54"+	Friable, pinkish white (75 YR 9/2) limesand becoming coarser at 40".

Since the texture of the surface soil cannot be determined in the field because of the high organic content, the textural class is based on the underlying soil. Size of the sand fraction varies with origin, the beach deposits being coarser or less well sorted than the dune sands. The exact thickness of the dark surface layer and the thickness and color of the transitional zone varies; their combined depth may range from 7 to 20 inches in the profiles observed. The shallower depths are usually found near the lagoon shores where this type passes into well developed Shioya loamy sand, or near the margins of taro pits. Where gravel is present it is often much more abundant in the surface layer and is there highly weathered and frequently "rotten". Its greater abundance may result from the more rapid solution of the sand. The presence of relatively unweathered surface gravel can usually be related to former house sites.

Included in this unit as mapped are small areas of associated less well drained soils with similar profiles as well as a few areas of the Arno gravelly loamy sand and transitions to the Shioya loamy sand that were too small to be separated.

In almost all cases the groundwater beneath this unit is fresh or nearly so and the taro pits are located in areas of this type and the related Arno gravelly sandy loam. The peat or muck of the taro pit bottoms and the varied soils of the excavated slopes are also inclusions in this unit as mapped. The "spoil" from the pits forms at most a scarcely discernible bordering ridge and the profile resembles that of the surrounding areas, although often shallower.

This unit and the following also form a major part of the "breadfruit zone". Individual trees or small groves mixed with tall coconuts are characteristic although not always present. Pandanus is usually common and even in well cleared groves small trees or sprouts of Allophyllus, Morinda, Guettarda and

Pipturus are abundant. Untended groves are occupied by secondary forest, composed of the above species with others such as Premna, Intsia, and on Arno Island, Ixora. Wedelia grows as a rank herb in openings and with Ipomoea tuba climbs liana-like in areas of secondary forest. The three ferns, Polypodium, Asplenium and Nephrolepsis are usually present, principally near the palm bases and on fallen palm logs; mosses are often abundant on these sites as well. Other ground cover plants vary with light intensity; under dense shade the ground may be quite bare or elsewhere sparsely vegetated with tree seedlings, Oplismenus, Ipomoea littoralis, small Tacca and scattered Thuarea and other grasses. In openings Tacca, Vigna and the grasses grow vigorously. The vegetation of the less well drained areas differs chiefly by the presence of Hibiscus tiliaceus and through the effects of dense shade.

Excepting the small areas of phosphatic soils, the Arno series with its less well drained associates are the most fertile soils of the atoll. The breadfruit grows rapidly here and bananas, papayas and limes grow fairly well, although severe iron chlorosis and probably other deficiencies retard their development when grown in cleared areas, as around the villages. Coconuts usually grow well on these Arno soils but on Arno Island itself a malady leading to early barrenness and death of the palms is associated with a portion of the unit. although not with its marginal occurrence or the bordering Shioya soils. In consequence, much of the interior there is now in breadfruit and secondary forests. According to the people this area was well populated for a long time prior to 1900; the malady was also present at that time and the coconut was maintained only by constant replanting.

The development and weathering exhibited by the Arno soils are evidence of their considerable age. They were formed under a native mixed broadleaf forest that was replaced in part by the indigenous agriculture and more or less

completely by "copra culture". Thus, their development cannot be related to the existing vegetation.

The generalized profile descriptions given by O. C. Rogers and by Alexander Spoehr for adjacent Majuro Atoll are essentially the same as that of the Arno loamy sand. C. S. Pearson, who has examined my photographs and samples of the Arno soil, states that it is the dominant type on Los Negros Island in the Admiralties.

5. Arno gravelly loamy sand: This unit resembles the previous soil but for the most part it has formed on coarse gravelly beach sands. These are usually of lagoon origin but some areas of highly fragmented outside shore deposits have also given rise to this type. The unit is usually associated with the Arno loamy sand in the wider island interiors but except on L'angar Island, is of much smaller extent on the islands mapped. It will probably be found more abundant in the chain of smaller islands around the windward rim of the atoll.

The profile is similar to that of the loamy sand except for the abundance of gravel, particularly in and on the surface horizon. Much of the gravel there is very rotten and readily crushed but the soil is always calcareous. The gravel of the deeper horizons appears little weathered.

Included with this unit as mapped are small areas of stony or coarse gravelly soils derived from mixed rampart materials but having a profile similar to the type. On Namwi Island a phosphatic soil resembling the Arno gravelly loamy sand in morphology (Profile #21) was not separated from it during the reconnaissance of that area.

The vegetation and uses of this unit are identical with those of the loamy sand except as it may occasionally overlie somewhat brackish groundwater. The presence of coarse material presents obvious difficulties in the use of hand tools.

6. "L'angar gravelly sandy loam": This name is used largely as a matter of convenience for the area of this unit actually observed is too small to warrant proposal of a new series. As the name suggests the unit occurs on L'angar Island where the type locality is marked by a protruding mass of old beachrock associated with a legend concerning discovery of the banana Jorukwor (see Part II).

A typical profile of this area follows:

0 - 20"	Very gravelly moist granular sandy loam, plastic when worked, with only a moderate content of organic matter. Surface dark gray when moist, gray (10 YR 5/1) when dry but superficially appearing 6/1 because of the abundance of lime particles, changing to light brown-gray (10 YR 6/2) near the bottom of the horizon. pH of dry samples 7.7 - 7.8. The larger gravel is softened and much of the smaller (less than 1") is porous or rotten.
20 - 35"+	Very gravelly sandy loam appearing lighter colored than the above but with a moderate content of organic matter. When dry, light pinkish gray (75 YR 6/1) in color; pH 7.9. The lower part is heterogeneous, consisting of dark soil material mixed with roots and coral fragments. Bottom of profile not reached.

This soil has a more loamy texture in the deeper layers than any of the well-drained soils examined. As borne out by the analyses in Table II, the organic matter distribution of this soil differs from that of the Arno series in the relatively low (6.5%) content of the surface layer and a surprisingly high (4%) content of the organic matter at the 30" depth.

The mode of origin of this soil is not known but its inland position and the highly weathered gravel indicate considerable age. It is tentatively regarded as a down-drainage associate of the Arno gravelly loamy sand that occurs around it.

The present vegetation consists of abundant Hibiscus tiliaceus with a few tall palms and volunteer coconut seedlings, Pipturus, Morinda and a few bananas. Ipomoea tuba and Wedelia are present as climbers. According to the people this area is the "best place" for bananas and formerly many were grown here.

B. Shallow and Stony Soils and Land Types.

7. Phosphate rock complex: Three small areas of brown phosphate rock occur on Tak-lib, Namwi and L'angar Islands. The soils formed directly on such rock are usually very shallow, ranging from 2-10" in depth. Both rock outcrops and pockets of deeper soil are common. The soil properties vary; in the center of Tak-lib the shallow soil is highly organic and appears mucky when wet whereas on Namwi and L'angar Island the soil is granular and contains considerable brown phosphatic sand.

A characteristic shallow profile from L'angar Island is:

0 - 4"	Black, highly organic granular sandy loam.
4 - 6"	Dark brown, granular loamy sand consisting of organic matter mixed with coarse phosphatic foram sand.
6 -	Brown phosphatic rock containing large unaltered fragments of coral.

The shallow soils comprise most of the phosphate rock complex but associated with them are: (1) small areas of unconsolidated brown phosphatic sand, (2) adjacent limesands with the surface layer enriched in phosphorus, and (3) adjacent sands or gravelly sands with an admixture of phosphate throughout the profile. So far as observed, none of these three were sufficiently widespread on the atoll to warrant separate mapping and because of their affinities they are here considered as a part of the phosphate rock complex. Characteristic profiles of the latter two follow:

Profile #12 - (L'angar Island) limesand with surface influenced by adjacent phosphate deposits:

0 - 10"	Gravelly loamy sand, high in organic matter, granular, black when moist, very dark gray (75 YR 3/1) when dry. pH 7.4. Very possibly not conformable with the underlying sand.
10 - 20"+	White or pinkish white limesand free of gravel.

This profile was observed when traveling with a group of the L'angar people and its relationship to the adjacent phosphate area was not investigated

further.

Profile #21 - (Namwi Island) "Namwi gravelly sandy loam", a gravelly limesand influenced throughout by phosphate rock:

0 - 6-9"	Well aggregated, very gravelly loamy sand or sandy loam, high in organic matter. Color very dark brown when moist, when dry dark reddish brown (5 YR 3/2) with particles of 5 YR 3/3 and 4/3 and some coarse white sand. pH 7.20. Earthworms abundant.
9 - 15"	Light brown (75 YR 6/3) loamy sand, less gravelly than above, consisting of white and brown stained foram sand mixed with organic matter. pH 8.1.
16- 25"+	Pinkish white (75 YR 8/2) limesand with some rounded coral gravel. pH 8.1.

In appearance this latter soil is very similar to the Arno loamy gravelly sand and, lacking chemical data, the small area on Namwi Island was included with the surrounding Arno soils. The very large content of extractable phosphorus (Table II), however, indicates that this soil should be distinguished as a phosphatic phase or as a separate series.

The phosphatic area on Tak-lib Island supports a much battered remnant of the original vegetation, apparently the only such on the atoll. A few large Pisonia, Cordia and Intsia were noted here, as well as breadfruit and the introduced kapok, Ceiba pentandra. On the other two areas the vegetation does not appear to differ from the secondary forest found nearby and on Arno Island. Small trees of Pipturus and Morinda are abundant along with Allophyllus, Pandanus and large breadfruit and coconuts. Ground vegetation is sparse in the dense shade but the ferns, Asplenium, and Polypodium, and the climber, Ipomoea tuba, were noted near the profiles.

The people accompanying us on Namwi Island recognized that the deeper soils of the complex are favorable for plant growth and stated that "many" bananas were grown in this locality before the war. The complex should be favorable for coconut and breadfruit wherever the roots can reach a sufficient volume of soil.

Samples of phosphate rocks from each of the three areas were collected and will be analyzed. The deposits are too limited in area and depth to have appreciable commercial significance but the softer materials could be used locally as fertilizer.

8. Dark shallow soils over sandstone: The only area of this unnamed unit occurs in the center of Bikareij Island. Because of the rock beneath and its closeness to the water table, this soil is only moderately well drained. A characteristic "profile" is as follows:

0 - 6"	Highly organic, black, somewhat plastic sandy loam or loamy sand.
6"	Calcareous sandstone, similar to that now found in the very shallow waters along the northwest shore of the island.

Elsewhere the soil depth varies from 0 - 11". A retting pit, or "tou", quarried in the sandstone (perhaps as a well) at the margin of this area shows a 6-inch layer of sandstone overlying about 6 inches of unconsolidated or soft material, which in turn rests on hard sandstone. It is probable that the roots reach the intermediate layer through crevices. After heavy rains the water in this pit was fresh to the taste but is said to be usually slightly brackish. This is probably characteristic of the area in view of the elevation and location.

The unit as mapped includes small areas of mucky soil, one of which is occupied by a tangle of Clerodendrum. The remainder of the unit is largely in poorly kept coconut groves with an understory of secondary forest species, Allophyllus, Morinda, Guettarda, Pandanus and, in less dense areas, volunteer coconut seedlings. This area appears suitable only for the culture of coconut and pandanus.

9. Stony and very stony complex: This term is used to designate the belt of the soils and land materials formed by the outward building of a well

marked beach rampart on the seaward side of the land. Also included are similarly located areas covered with weathered irregular fragments of coral reputedly - and very probably - deposited by ancient typhoons. A "typical" cross-section from the windward beach inland, the synthesis of many observations, would appear as follows:

(a) Present beach rampart; recently deposited coral cobbles and rounded plates with coarse gravel and sand mixed in the lower parts; surface commonly six to ten feet above high tide.

(b) Twenty-five feet inland from (a); surface of rounded cobbles as at (a) but darkened by weathering; vegetation is tall Scaevola passing into Scaevola-Pandanus or Scaevola-coconut mixture inland.

(c) Hundred feet inland from (a); cobbles markedly weathered and covered with algae; many have lost their smooth and rounded surface. Vegetation is coconut plantation with Polypodium, small Wedelia and sprouts from cut stumps of Scaevola, Guettarda and Morinda.

(d) Two hundred feet inland from (a), near junction with sandy soils. Rounded cobbles are no longer recognizable; ground surfaced with very irregular weathered fragments of coarse gravel and small stone dimensions, heavily coated with black algae. Dark soil visible between fragments. Vegetation is coconut plantation, occasionally with breadfruit. Polypodium, Nephrolepsis, and Asplenium are common, especially around the bases and moss-covered lower trunks of the palms. Other groundcover plants are chiefly sprouts and seedlings of Morinda, Allophyllus and Pipturus. The land surface is commonly two to three feet lower than at (b).

The profiles corresponding to the above stations show a progressive increase in the amount of organic matter and content of the finer particle sizes, associated with increased disintegration of surface rock. The change from (a)

to (b) is slight, principally the addition of a small amount of organic matter between the coarser particles. At (c) a black organic gravelly loam occupies the space between the weathered rock and all of the porous fragments are well penetrated by roots. At (d) the surface soil approaches that developed from gravelly lagoon deposits, although the deeper layers are not much altered. The coarser rock has broken down to weathered gravel and the percentage of sand and finer fractions have increased. Organic matter makes up 20% or more by weight of the material less than 2 millimeters in size, binding the mineral particles into aggregates.

Periods of rapid outbuilding, of stabilization or of beach erosion, as well as the overwhelming effects of infrequent typhoons, may disrupt any such orderly sequence and the "typical" cross-section above is less common than various atypical forms.

This unit appears fairly well adapted to coconut culture although the outer margins are often obviously less suitable than the remainder. In many cases the palms would probably benefit by retention of the surface organic matter and by effective windbreaks along the beaches.

C. Peats and Mucks.

10. Mangrove peat: This is a somewhat fibrous woody peat, moderately well decomposed and saline, formed under Bruguiera conjugata. When moist, it is dark red in color, drying to dark reddish brown (5 YR 2/2 - 3/2). The odor of hydrogen sulphide is present in the deeper layers. The fresh peat commonly has a pH of 7.2 to 7.4 but this changes to pH 5.6 to 5.9 upon drying. This type is usually less than 2 ft. in depth but the center of the large deposit on L'angar Island is deeper than 40 inches. The shallower areas are often somewhat more decomposed and may contain lime fragments. Limesand particles 1 to 2 mm. in size effervesce very slowly with hydrochloric acid,

indicating a considerable degree of weathering. The groundwater fluctuates with tidal changes but is usually 1 to 2 ft. below the surface. The principal areas of occurrence are on L'angar, Tinak, and Bikareij Islands.

The vegetation is unusual, approaching a monotype of Bruguiera. Along the margins Lumnitzera, Pandanus and the shrubby Clerodendrum may occur but transition from the upland is ordinarily abrupt and, except for a few epiphytic Asplenium, the interior vegetation is wholly Bruguiera. More than one age class may be present but the youngest, forming a low ground cover, is apparently short-lived in the dense shade. The forest is otherwise quite open beneath the canopy and presents a quite unusual aspect with innumerable crabs scuttling about the roots and "knees" that protrude through the cushiony reddish peat. This type is useful only as forest. The Bruguiera is a wood of value, strong and durable in contact with the soil and the younger stems provide long straight poles.

11. <u>Mangrove shallow peat and rock complex</u>: This unit sometimes borders areas of Mangrove peat and occupies the smaller salty depressions. The most common occurrence is a peat over and in the interstices of coral rubble or fissured rock; small areas of rock outcrop and of peat and muck mixed with coral gravel are also included within this type. The organic matter, if peat-like, resembles the Mangrove peat described above; the mucks, however, are blacker, more decomposed and perhaps less saline. The principal areas of occurrence are L'angar Island and Tinak Island and the borders of the north inlet on Bikareij Island, but small patches of an acre or less are met with elsewhere.

The dominant species is Bruguiera which may occur in pure stands. On Bikareij and Namwi Islands only, Sonneratia may be mixed with the Bruguiera. Elsewhere Lumnitzera and, on the margins, Pandanus are minor associates. The only use of such areas is as forest although retting pits are often located

within them.

12. Mangrove muck: This unit is properly a land type rather than a soil and occupies too small an area to warrant much comment. It consists of finely divided organic matter principally derived from Bruguiera, or Bruguiera and Sonneratia, mixed with limesand; it is saline, has a high water content and is flooded or nearly so at high tide. Mangroves grow only on the "drier" margins of the unit but the roots of Sonneratia penetrate outward in it for some distance.

The only appreciable area of this type occurs in the deeper basin at the south end of the north inlet on Bikareij Island. A portion of this is reputedly "bottomless", men having thrust sticks tied together to a depth of 75 feet from a canoe without reaching bottom. This had a familiar ring and our investigations showed a depth of some 4 feet of gel-like muck overlying rock in the center of the area. This is covered by perhaps six inches of water at low tide. On exposed margins where the spike-like Sonneratia "knees" arise the muck is two feet or so thick over sand.

Muck from beneath this surface smells very strongly of hydrogen sulphide. A sample taken from the center was dull red in color when removed but although tightly compacted soon turned gray throughout the entire mass. This area is noteworthy chiefly because of reputed effects of the muck on human skin (Appendix C).

13. Coconut-pandanus peat: This unit occupies an inland swamp on Ül-en' Island and is the principal type found in the old taro pits on Arno Island. The peat is shallow, usually 1 to 2 feet deep and fibrous, the more decomposed portions bound together by a mass of living and dead roots.

A description of the typical profile (#24, Arno Island) is:

0 - 24"	Well decomposed peat with many root fragments; pH 6.5 at time of sampling, 5.4 after drying. Color after drying and grinding is brown to dark brown (7.5 YR 4/3). Water level at two inches at time of sampling following heavy rains; it stood much lower on a previous visit.
24" +	Mucky limesand.

Conductivity measurements on the dry samples indicate that both the Arno and Ül-en' occurrences are fresh-water peats, although it is possible that the Ül-en' swamp may occasionally be subject to flooding with somewhat more brackish water. Included with the unit indicated on the map of Ül-en' is a small area of shallow black muck at the southeast margin of the swamp. In addition to woody sprouts, Wedelia, Colocasia and Cyrtosperma were growing at this point. People stated that these taros could not be grown elsewhere in the swamp although the water had "not very much salt".

On the remainder of the Ül-en' swamp the vegetation is coconut grove with an abundant undergrowth of pandanus. Wedelia and sprouts of Morinda and Allophyllus occur on the slightly higher rises. The peat offers poor footing for the coconuts; fallen logs are numerous and most of the standing trees are curved. Coconut usually grows on the margins rather than directly on the surface of the taro pit peats of Arno Island but the pandanus is in both positions. Here, too, Hibiscus tiliaceus is often a bordering tree and other secondary forest species around the margins contribute some organic matter. In both areas mosses and ferns, Polypodium, Asplenium and Nephrolepsis are abundant on fallen logs although the ferns perhaps do not reach maximum development here. Dryopteris goggilodus, the "kinnen menuel", forms dense colonies in the Arno pits but was not seen elsewhere. Similarly Eleocharis geniculata was observed only on Ül-en' Island where it was fairly common on the peat surface near profile #26.

It is not known whether these peats can be utilized for taro culture. Both areas are subject to immersion after heavy rains and it is said that an attempt to replant some of the Arno pits failed because the small plants were covered with water. The potential fertility of the peat is high and cultivation, exposure to sunlight, etc., would gradually change the peat to the well decomposed muck in which taro normally grows. Palms are apparently growing well in the

Ül-en' peat although the yields are unknown. The possibility of excavating this peat for gardens is mentioned later.

As nearly as can be determined, the Arno pits were abandoned very early in the century and thus the rate of peat accumulation appears to have been extraordinarily rapid. According to Ralph McCracken, peat development in phosphate mining excavations on Angaur Island, in the Palaus, proceeds at a similar rate.

14. Taro pit mucks: If the area involved were more extensive a taro pit complex might be recognized. The steep inner slopes of the taro pits have been subject to slope wash and other disturbance from human traffic and the rooting of hogs. Not uncommonly coconut husks, fronds and brush from grove clearing are thrown over the edge and usually incompletely burned.

The pit bottoms are usually artificial mucks created by long continued additions of organic matter for taro culture. The mucks vary considerably in the admixture of mineral material and in relative "wetness". The groundwater is fresh and its level fluctuates with the tide, the maximum often being with a foot or less of the surface. After heavy rains many of the pits are shallowly flooded for a few days. As noted above, coconut-pandanus peat has formed in the long abandoned Arno pits. Elsewhere abandonment has been less complete or the water level unfavorable for peat accumulation. Taro culture continues in some pits.

A typical profile of a taro pit muck (#5, Ine Island) follows:

Surface	Scattered breadfruit leaves and seedlings of colocasia and a grass.
0 - 10"	Mucky limesand with some coral gravel less than 1 inch in diameter. Matrix very dark gray flecked with light lime particles. pH of moist sample 7.6.
10 - 32"+	Light gray changing to white sand, the organic matter content diminishing gradually with depth. pH 7.4 at 30 inches. Strong smell of hydrogen sulphide at 30 inches. Groundwater level at 28 inches when sampled but the following day, with the rising tide not yet full, at 15 inches.

Except on Arno Island the abandoned pits are often occupied by woody vegetation, such as breadfruit on "drier" sites and Hibiscus tiliaceus. One or two pits on Ine Island were completely dominated by Cyperus odoratus. The mucky pits could be readily returned to taro culture if the people wished to do so. In their present condition the drier mucks and pit margins are well suited for bananas but are utilized to only a limited extent for this purpose.

D. Miscellaneous Land Types.

These include the beaches, limesand drifts, and embayments or inland "flats" of sand, rubble or cemented rock. Since the fragmentation of the long eastern island by the 1905 typhoon much of the remaining land has been reconnected and augmented by wave heaped sands; the same process can be seen elsewhere as well. Where the surface of these rises above tide level it is vegetated by Scaevola, Messerschmidia and coconut seedlings, all often chlorotic in the early stages.

In the course of land formation or repair low areas of the island platform are sometimes cut off between the rampart or gravels thrown up along the seaward coast and the existing land or sand drifts on the lagoon side. This is the probable origin of many of the existing mangrove swamps and certain interior lowlands, such as that near Kinäjong. Rampart formation following typhoon damage has cut off two small basins on Aljaltüen' Mätol-en' and Enëräen' Islands; these are not yet vegetated. The larger "flats" of Namwi and Bikareij Islands seem to have been enclosed by extension of existing lands. As long as such areas are open to the sea the higher tides bring in sediments and occasionally rework the surface. Sand banks formed along the margin are rapidly stabilized by vegetation and thus young soils may come to occupy the interior as well as the periphery of an island.

Not otherwise described is the buried soil found 260 feet inland from the sea-beach near Ine Island (Profile #4, Appendix B). The present surface soil is

characteristic of a moderately well drained associate of the Arno gravelly loamy sand but extending from a depth of 35 inches to over 58 inches below the surface is a dark horizon containing organic matter. According to Lijömmar of Ine, a typhoon in the "time of his grandparents" threw up rock along the coast at this point and conceivably burial of the original profile occurred at that time. If Lijömmar's statement is taken literally, however, the maximum age of the present surface profile could scarcely be greater than 125 years, which appears too slight for the development noted.

SOME CHEMICAL PROPERTIES

The results of some chemical analyses of the mineral and organic soil samples from Arno are given in Table II. Descriptions of the profiles, identified by numbers, are given in the preceding section and in Appendix B. The material taken for analysis was that passing a 2 mm. sieve except for the organic samples of profiles #16 and #24 which were ground. pH was determined by glass electrode, soluble salts by conductivity measurements, total nitrogen by Kjeldahl, organic matter by the rapid microchemical methods of Peech (Soil Science 59:25-38, 1945), and the "readily soluble" amounts of other elements by the methods of Peech and English based on the use of Morgan's extracting solution (Soil Science 57:167-195, 1944).

pH, Calcium and Magnesium

As expected, the mineral soils are all slightly alkaline in reaction ranging from 7.2 to 7.5 in the highly organic surface soils to a maximum of pH 8.7 in the unweathered material lacking appreciable organic matter. These soils all effervesce with acid and hence analyses for available calcium were not made.

Dried samples of the organic soils have an acid reaction whereas in the field, using indicators, reactions vary from essentially neutral to slightly alkaline. Thus for the same samples:

Table II. CHEMICAL ANALYSES OF SOME SOILS FROM ARNO ATOLL

Profile No.	Soil type or Designation	Depth of Sample	pH	Organic Matter %	Total N %	OM/N	Pounds per acre P	NO_3 N	NH_3 N	Mg	K	Mn	Fe	Al	Soluble salts $K \times 10^5$
		Inches													
25	Arno loamy sand	0-6	7.45	16.68	.88	19.0	80	100	40	750	110	8	1	5	80
	Arno Island	6-11	7.55	11.32	.59	19.2	25	30	40	425	63	8	1	5	60
		14-19	8.40	.28	.04		25	8	18	5000	18	5	1	5	19
		24-30	8.65	.14	.04		40	8	20	3750	15	5	1	5	17
23	Arno loamy sand	0-6	7.55	22.48	.98	23.0	10	60	25	50	63	8	1	5	74
	Arno Island	12-18	8.25	.20	.05		25	8	15	3000	19	5	1	5	20
		30-36	8.40	.10	.05		25	5	15	4500	22	5	1	5	18
29	Arno loamy sand	0-6	7.50	19.04	.88	21.6	120	20	45	950	126	40	1	5	45
	Jab'u Island	18-24	8.40	.20	.04		50	5	25	4000	14	5	1	5	21
		30-36	8.50	.24	.06		60	5	22	5000	15	5	1	5	21
6	Arno gravelly loamy sand	0-6	7.40	32.92	1.16	28.4	110	100	50	1800	203	25	1	5	104
	Ine Island	6-12	7.50	20.44	.70	29.2	25	40	45	750	80	20	1	5	74
		20-26	8.35	.28	.04		30	5	20	5000	18	5	1	5	15
4	Moderately well drained associate of Arno very gravelly loamy sand	0-8	7.55	16.88	.73	23.1	25	25	35	50	135	25	1	5	46
	Ine Island	20-28	8.05	.80	.08		20	8	18	1600	23	5	1	5	24
		38-46	7.85	3.84	.13		8	8	25	200	45	5	1	5	38
21	"Namwi gravelly loamy sand"	0-7	7.20	20.44	.67	30.6	860	80	45	1120	286	5	1	5	104
	Namwi Island	10-16	7.50	3.44	.30		400	20	22	3800	45	5	1	5	57
		20-25	8.10	.52	.07		280	10	25	5000	31	5	1	5	32
12	Phosphate influenced associate of Arno sandy loam. L'angar Is.	0-8	7.40	19.36	.99	19.6	210	70	45	1120	98	8	1	5	70
11	L'angar gravelly loamy sand	0-6	7.70	6.52	.41	16.2	80	45	22	700	57	8	1	5	49
	L'angar Island	14-20	7.80	5.34	.34	17.3	50	40	25	950	45	5	1	5	62
		29-35	7.90	4.02	.28	14.4	50	40	22	1000	55	5	1	5	115

Table II. CHEMICAL ANALYSES OF SOME SOILS FROM ARNO ATOLL (continued)

Profile No.	Soil type or Designation	Depth of Sample	pH	Organic Matter %	Total N %	OM/N	Pounds per acre								Soluble salts $K \times 10^5$
							P	NO_3 N	NH_3 N	Mg	K	Mn	Fe	Al	
		Inches													
14	Shioya sand. L'angar Island	0-7	7.95	1.82	.16		20	20	25	4250	31	5	1	5	29
27	Shioya sand with recent overburden	2-1/2-4	8.25	.74	.08		25	8	20	4000	25	5	1	5	18
	Jab'u Island	0-4	8.25	.70	.08		25	10	15	4000	19	5	1	5	20
		16-20	8.70	.08	.04		25	5	18	3000	12	5	1	5	17
16	Mangrove peat, L'angar Island	0-6	5.90		1.51		1600	35	130	12000	976	5	1	5	2700
		16-22	5.75		1.24		1200	15	100	16000	1200	5	1	5	3000
18	Mangrove peat, Tinak Island	0-6	5.65		1.82		760	15	130	19000	1400	5	1	5	3000
26	Coconut-pandanus peat, Ul-en' Is.	0-8	6.25		2.60		280	30	190	2000	436	5	1	5	225
24	Taro pit coconut-pandanus peat, Arno Island	0-8	5.40		2.95		320	15	220	1400	310	5	1	5	345

Profile #	pH Fresh	Dry
26	6.8	6.25
18	7.2-7.4	5.65
24	6.5	5.4

Changes of this magnitude or greater upon drying in mineral soils containing sulfur have been reported and are attributed to oxidation of the reduced forms to sulphates. This sequence is a very likely one in our samples and probably accounts for the increased acidity noted. The two samples of coconut-pandanus peat, #26 and #24, are the only soils on the atoll that were acid at the time of collection.

As might be expected from the discussion of parent material, readily soluble magnesium is relatively high in all soils.

Salt Content

The content of soluble salts is expressed as specific conductance, $K \times 10^5$ at 25° C, of a 1:2 soil:water mixture (by weight). As a basis for comparing the samples of mineral soils from Arno, unfertilized leached soils of the humid regions commonly have K-values below 15 whereas heavily fertilized greenhouse soils may range from 100 to 200. A K-value of about 200 is about the maximum permissible for salt sensitive plants and values greater than 300 result in severe injury to common greenhouse plants. High organic matter contents raise the critical level at which injury occurred. For soils flooded with sea water the critical K-value is 100 for sensitive plants since the toxicity of a single salt is greater than that of mixtures.

Thus values for mineral soil in Table II fall within a range well below the level of plant injury. The higher values of the dark surface soils of the Arno and similar series is due in part to the content of soluble nitrogen salts.

The allowable levels mentioned above do not apply to the organic soils because of their very high moisture contents. The two samples of coconut-

pandanus peat fall well within the usual range of "fresh water" peats. The mangrove peats, of course, are highly saline.

<u>Organic Matter and Nitrogen</u>

The extreme color contrast between the surface and subsoil in the Arno series and its associates is paralleled by the contrast in organic matter content. That of the surface soils is surprisingly high, ranging from over 16 to nearly 33% in the surface six inches. Where this horizon is sufficiently deep for a second sample above the transition zone it, too, is high. Thus the average content of organic matter to a depth of eleven inches in profile #25 is 14% and 26.7% to a depth of twelve inches in profile #6. These values do not take into account the gravel excluded in sample preparation. Organic matter decreases very abruptly through the narrow transition zone and the white lime-sand beneath contains only a fraction of 1%. The notable exception is profile #4 where increased organic matter and nitrogen indicate a former soil surface long since buried by the material on which the present soil developed. Total organic matter as mass per unit area cannot be calculated without data on bulk density and excluded matter, but it would seem to be of the order of 200,000 to 400,000 lbs. per acre.

As already mentioned, the L'angar gravelly loamy sand has a relatively much lower content of organic matter in the surface horizon but the deepest samples taken still contain some 4%; again these values are on a gravel-free basis. The two samples of Shioya sand contain low amounts of organic matter.

In mineral soils total nitrogen generally parallels organic matter with the ratio between the two indicating the degree of decomposition. The OM/N ratios calculated do not depart far from 20, which is usually considered characteristic of well decomposed "humus". As might be expected, the amounts of "available" ammoniacal and nitrate nitrogen are moderately high in the dark surface soils and low in both the deeper horizons and in the Shioya sand.

Organic matter in the peat samples will be determined later but may be expected to exceed 80%. The total nitrogen contents are high, ranging up to nearly 3% for a sample from a taro pit on Arno Island. Of the available nitrogen forms, ammonia is far in excess of nitrate.

Phosphorus

Estimation of readily soluble phosphorus is an empirical procedure at best and the extractant used (pH 4.8) is not well adapted to calcareous soils. Thus the data presented characterize phosphorus status to only a limited degree. The low organic limesands of the subsoils and Shioya soils usually fall within a range of 20 to 30 lbs. P/acre (= 10-15 ppm) whereas the content of the dark surface layers is usually much higher, the notable exception being the 0-6" sample of profile #23 from the area of short-lived coconuts on Arno Island. The samples from profile #21 and #12, adjacent to phosphate deposits contain relatively large amounts of the element.

The quantity present in peat is generally several-fold greater than in mineral soils but by humid temperate region standards the phosphorus levels of the Arno peats are high.

Potassium

As with phosphorus the low organic limesands yield a minimal amount of potassium to the extracting solution. This value is about 15-25 lbs. per acre whereas the range in surface soils, having much higher exchange capacity, is commonly 50-200 lbs. per acre. These levels would be considered adequate for plant growth if they can be sustained but information on the reserve potassium is needed.

The mangrove peats are very high in potassium, reflecting the influence of sea water, and the coconut-pandanus peats are reasonably high.

Iron, Aluminum and Manganese

The constant amounts of iron and aluminum in Table II are the minima reported by the procedure used and thus any lesser variations are concealed. A much greater range is shown by the manganese contents; the minimal amount, less than 5 lbs. per acre, characterizes the low organic limesands, the peats, and the high phosphorus soils but the remaining surface soils contain 5 to 49 lbs. per acre.

SOME EFFECTS ON PLANTS

No field moisture determinations were made but some obvious relationships may be noted. The moisture sources of importance are soil water, held by capillary forces throughout the soil, and the ground water, which is of unusual importance here because of the proximity to the surface and its possible salt content. Shallow rooted plants and those growing some distance above the ground water, as on dunes, must depend exclusively on water held in the soil; only an actual examination of the root system will reveal to what extent the deeper rooted plants normally reach the region affected by the ground water. It is quite possible to have a considerable depth of soil containing salt-free soil water overlying brackish groundwater.

The moisture holding capacity of the coarse textured soil is usually assumed to be low but in the surface layers this property is augmented by the content of organic matter. The possible moisture capacity of porous coral has already been suggested. During our stay on Arno, the longest period without rain was not more than a few days and the soil in excavations was never thoroughly dry. Some plants exposed in openings showed temporary wilting during the brief periods of dry sunny weather but recovered overnight. Thus, to judge by mere observation, soil moisture was not a direct factor in plant survival, other than for seedlings, during the June to August period, although it certainly may have

influenced plant growth and competition. Observations in the drier months, however, might well reveal critical soil moisture levels.

In many areas the ground water level is closer to the surface and here, the problem is obviously not water but salt. Although the conductivity data in Table II indicate how well rainfall removes soluble salts from the upper soil layers they do not fairly represent conditions for plant growth on a considerable part of the atoll. Many areas of Shioya sand and loamy sand, and the outer parts of the stony land complex undoubtedly have brackish ground water. Moreover, groundwater salinity often increases during the later winter "dry" season. In this environment salinity, like soil moisture, should be considered a fluctuating soil property for the critical levels that determine plant survival may persist for only brief periods.

The question of "atmospheric salinity" is not considered here although it is fairly obvious that salt spray can influence plants near windward coasts and under unusual storm conditions. As Mr. Cox has pointed out, water samples from the wells of Ine and Arno Islands and from cisterns on Ine have a very low chloride content indicating no appreciable spray contamination on those leeward islands.

Apart from variations due to the seasonal rainfall differences, it is evident that the pattern of groundwater salinity will be affected by permeability of the substrate and by the land width, height, etc. Some sensitive plants may grow almost to the shores where the outward flowing sheets of fresh water prevents movement of salt water inland. Thus breadfruit, which is not considered salt tolerant, has been observed within 35 ft. of a low beach on Ül-en' Island.

The several considerations mentioned above and the very considerable differences in soil fertility levels suggested by Table II indicate that salinity, important as it is in controlling plant distribution, should not be overstressed.

Thus a plant species or community growing in an area of limesand or Shioya sand may well be exposed to atmospheric and groundwater salinity but these soils are also characterized by low nitrogen, exchange capacity, potassium, etc. Thus the presence of the plant or community elsewhere may suggest low fertility levels, salt content, or both. In a similar vein, the occurrence of certain plants in the island interiors only may be a response to the higher fertility levels there as well as to the salt-free groundwater.

The yellow leaved palms seen on several areas were attributed to excess salinity, largely on the basis of land position, although the possibility of nitrogen deficiency cannot be excluded. A surface soil sample from one such area showed little salinity, a not unexpected finding considering the high rainfall of the period previous to sampling.

Another coconut malady affects an appreciable area in the interior of Arno Island. As already noted, a surface soil sample from a badly affected spot there is unusually low in readily soluble phosphorus. Considering the long occupancy of the land and the relatively high phosphorus demand of the coconut, the possibility of phosphorus deficiency on the area must be considered.

On Mokil, Bentzen (Pacific Science Board CIMA Report, 1949) found an area in the center of each of the three islets composing the atoll on which coconuts were no longer productive. The largest, on Urak Island, is known to have grown breadfruit prior to 1890 when it was cleared and planted to palms. For some years it produced well but yields declined after 1913 and by 1925 it was given up as a commercial venture, although the palms still stand. Inasmuch as Bentzen mentions neither dead trees nor foliar symptoms this condition appears to differ from the Arno syndrome, at least in severity. Both, however, occur on island interiors, cropped to coconuts and in both areas breadfruit trees still grow well. It seems likely that similar maladies will be found on other atolls.

As might be expected, iron deficiency is common on Arno in village areas and clearings or wherever organic matter additions are lacking. Some of the sensitive exotics such as banana, lime and hibiscus become strikingly chlorotic but more or less severe symptoms were noted in fourteen other genera, native and introduced. Experimentally, this condition in the banana was overcome by suitable applications of iron to the leaves but a more practical means is through organic matter additions and mulches. This deficiency may influence plant competition on areas of exposed limesands since Thuarea, Vigna, Tacca, and Centella are at least moderately affected. Under closed forest conditions symptoms are rarely noted.

Mr. Anderson sent a variety of vegetable and flower seeds with our party as a gift to the Arno people. The resulting plantings observed were largely failures either because of cultural or soil difficulties.

A small "garden" was established in Ine Village with the hope of detecting soil factors affecting plant growth. The area had been long cleared and hence presumably did not correspond to similar areas of Arno loamy sand under forest. Onions, radishes, lettuce and tomatoes failed after germination and slight initial growth; pole beans, corn and curcurbits were stunted and their eventual failure appeared certain. Growth was not greatly affected by applications of nitrogen (as ammonium sulphate), potassium or boron. Iron chlorosis masked other symptoms in the tomatoes and curcurbits; the remaining species did not display characteristic phosphorus deficiency symptoms. These considerations together with the prevailing alkalinity and the data of Table II suggest minor elements, other than boron, and possibly phosphorus as the limiting factors for growth.

Coconut-pandanus peat from a taro pit on Arno Island (Profile #24) was potted and sown to tomatoes, lettuce and onions. A photograph by Dr. LaRivers a few weeks later shows that tomatoes and lettuce grew rather well in the peat

fertilized with ammonium sulfate, potassium chloride and crushed phosphate rock, whereas the onions, a salt-sensitive crop, grew much better in the unfertilized material. Wherever peat deposits occur near village areas they could be excavated to surface seed beds and very small garden spots for plants not readily grown otherwise.

On the basis of observations thus far there is no reason why a large number of exotic plants cannot be grown on the atoll soils under garden condition. Alkalinity of the mineral soils will exclude several but the neutral peat can provide a medium for some of these. In the absence of specific information on limiting elements "complete" fertilizers including minor elements seem necessary, or in their stead, heavy applications of organic matter incorporated with the soil or as mulches. Under the conditions of Arno the latter is the only feasible means. In addition to soil factors other cultural requirements, such as adapted varieties, pest control and protection of small seedlings against rain, wind and drying must be considered. Recommendations for the peasant style agriculture of Arno necessarily must be very different from those employed under a more modern agriculture.

DISTRIBUTION

Maps

Soil distribution was mapped in detail on the larger islands. In some instances mapping was limited by time or heavy rains and has been supplemented by notes and sketches made on preliminary tours with the local citizens. The attached maps have been prepared by transferring field sheets and notes to base maps enlarged from 1/30,000 aerial photographs. Unfortunately the photographs were not available in time to be of use when most of the field mapping was done and subsequent interpretation from them has been limited by their scale and quality. In some cases the mapping precision is not commensurate with the relatively large scale of the maps.

LEGEND FOR SOIL MAPS

SOIL AND LAND TYPES

Light colored soils of narrow lands and shores	Sl	Shioya loamy sand
	Sg	Shioya gravelly loamy sand
	Ss	Shioya sand
Dark soils of the island interiors	Al	Arno loamy sand
	Ag	Arno gravelly loamy sand
	Ll	L'angar gravelly sandy loam
Undifferentiated soils and land types	P	Phosphate rock complex
	Ts	Dark shallow soils over sandstone
	S.C.	Stony land complex
Peats and mucks	Mp	Mangrove peat
	Msr	Mangrove shallow peat and rock complex
	Mm	Mangrove muck
	Cp	Coconut-pandanus peat

OTHER SYMBOLS

Limesand shore deposits

Dune

Beach rampart and juvenile phases of stony land complex

Beach sandstone

Reef rock, conglomerate and sandstones

Depression

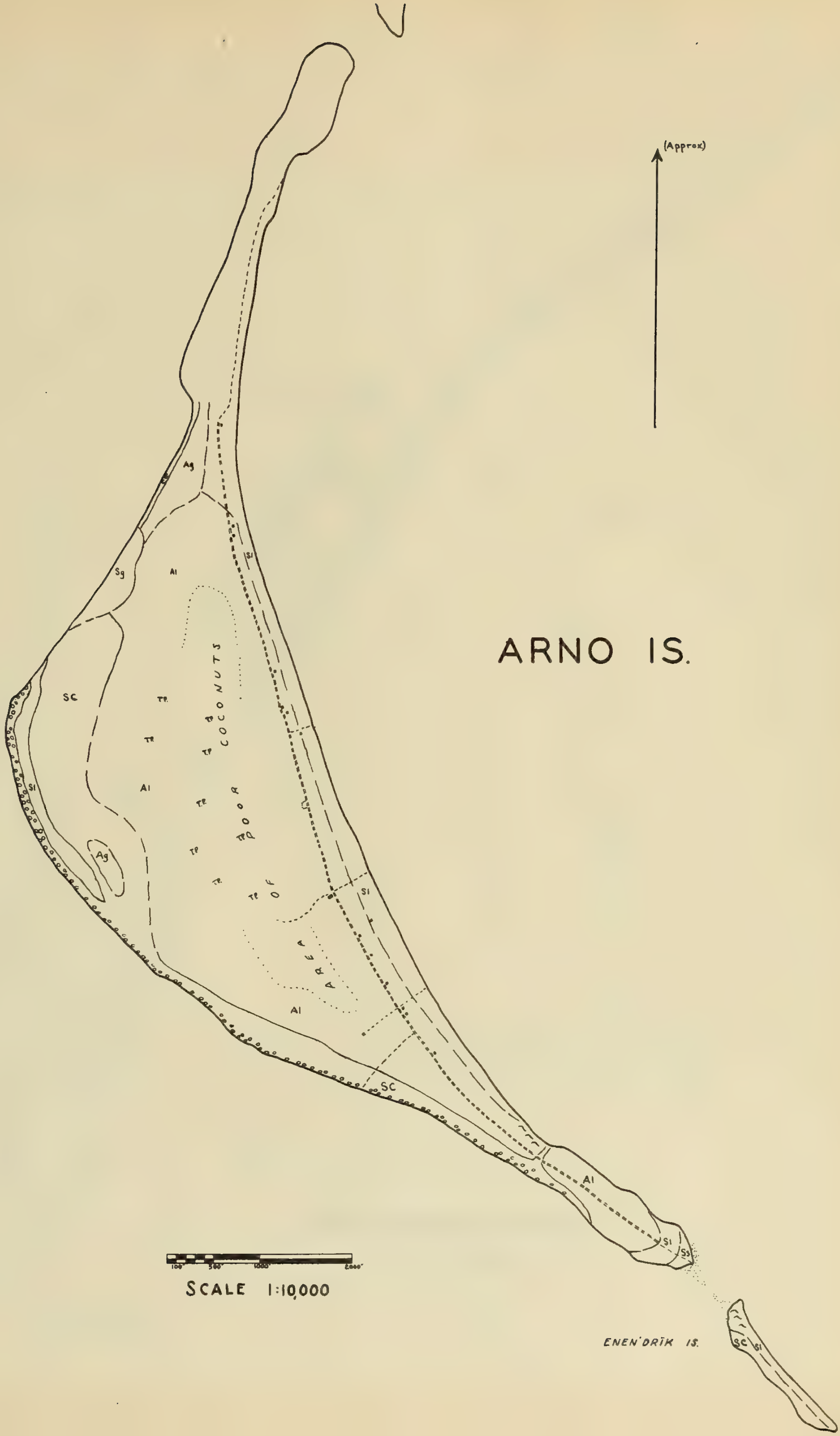
Erosion escarpment

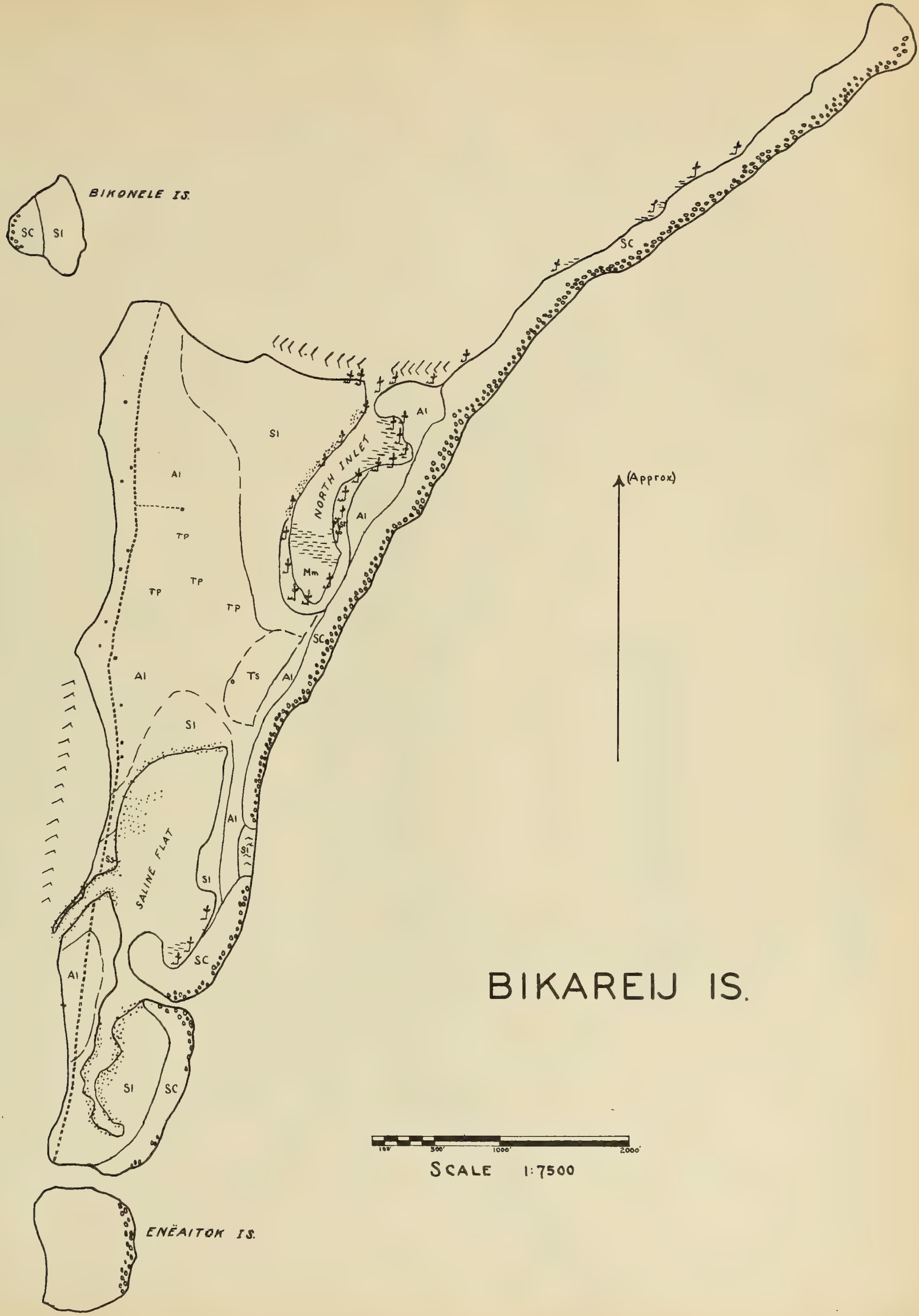
Well

TP Taro pit area

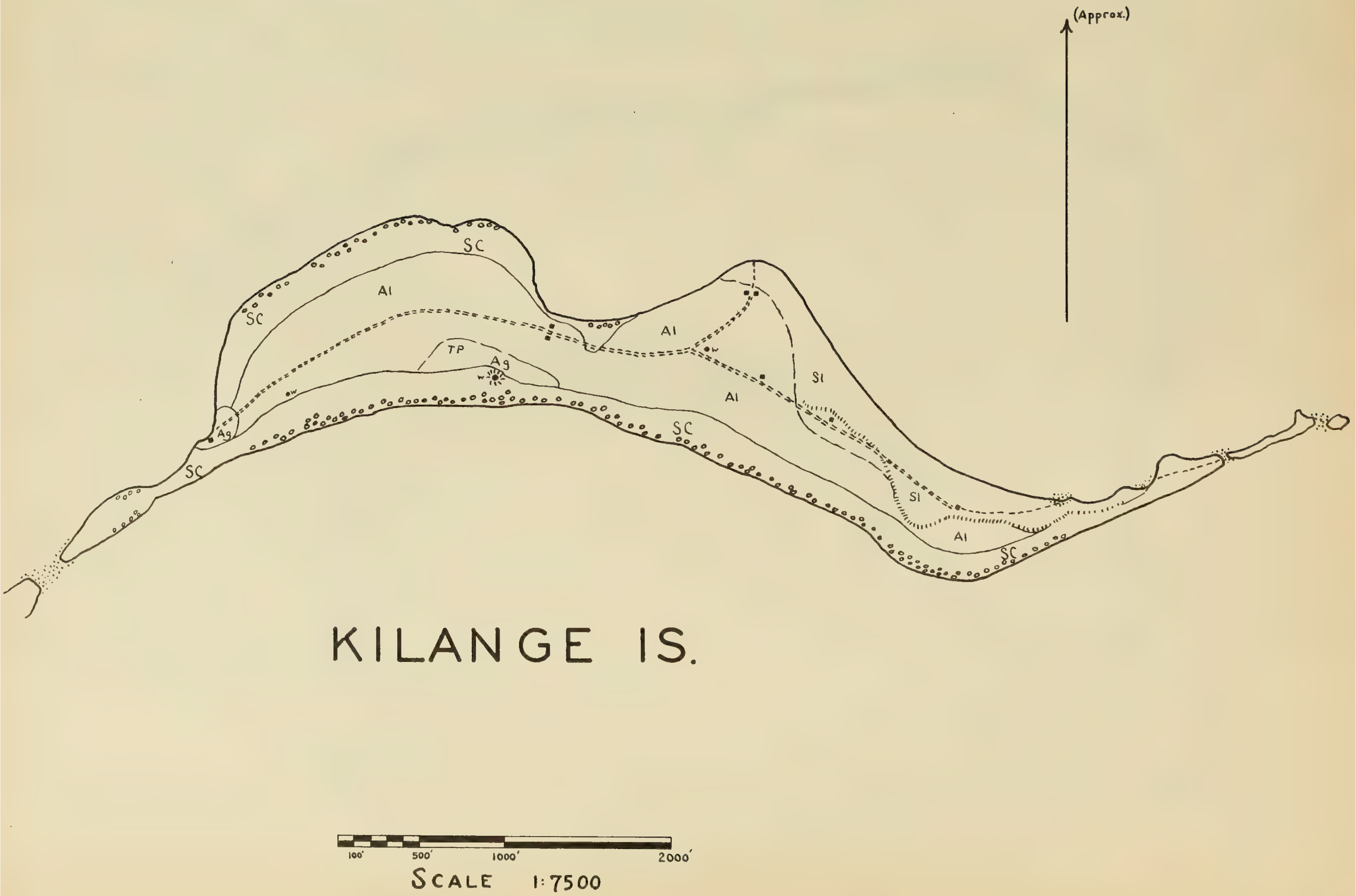
Mangroves

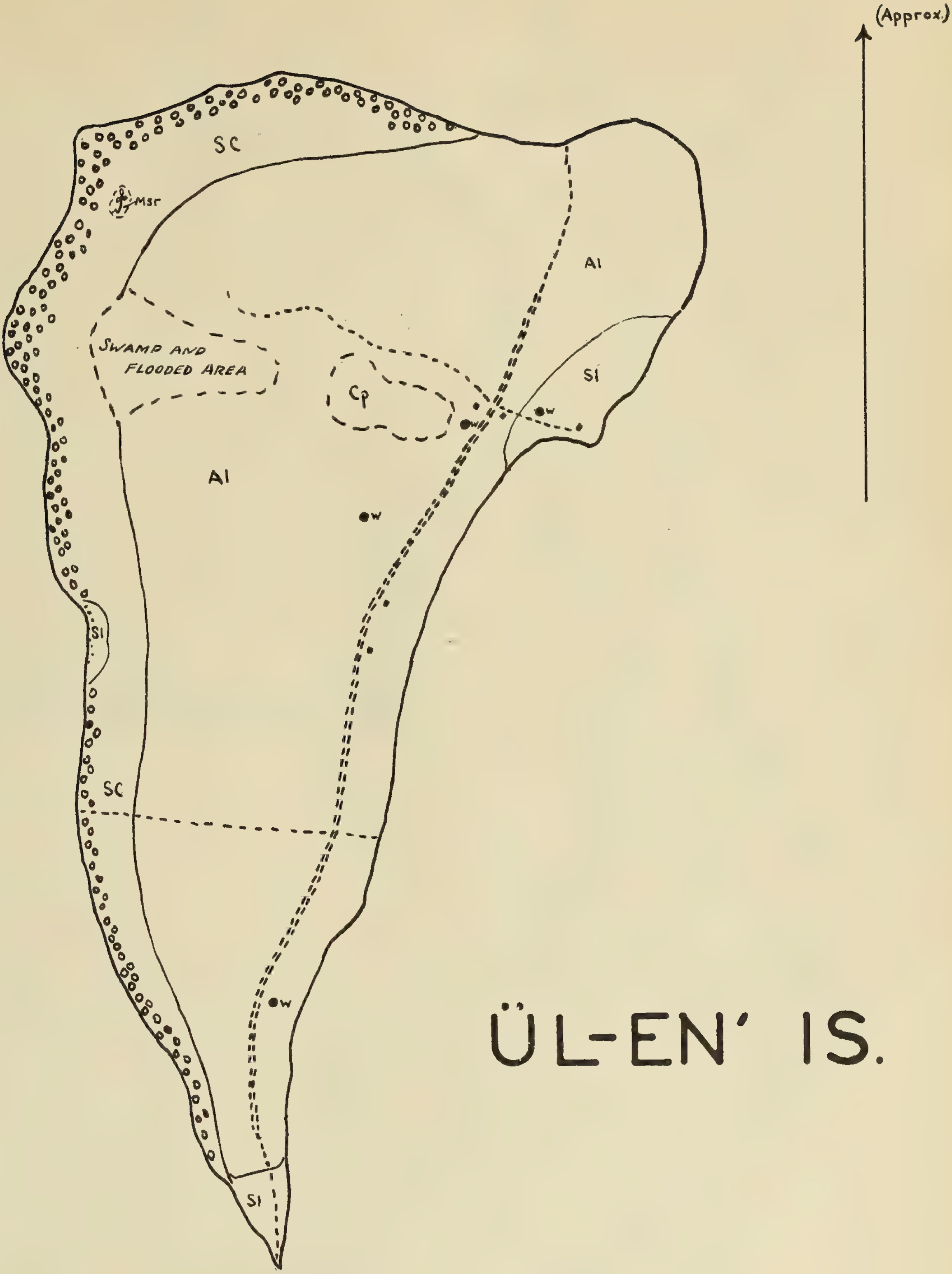
Main walks and trails


ARNO IS.
(Approx)
AREA OF POOR COCONUTS
Ag
Sg
Al
SC
Sl
TP
Ss
SCALE 1:10,000
ENEN'DRIK IS.

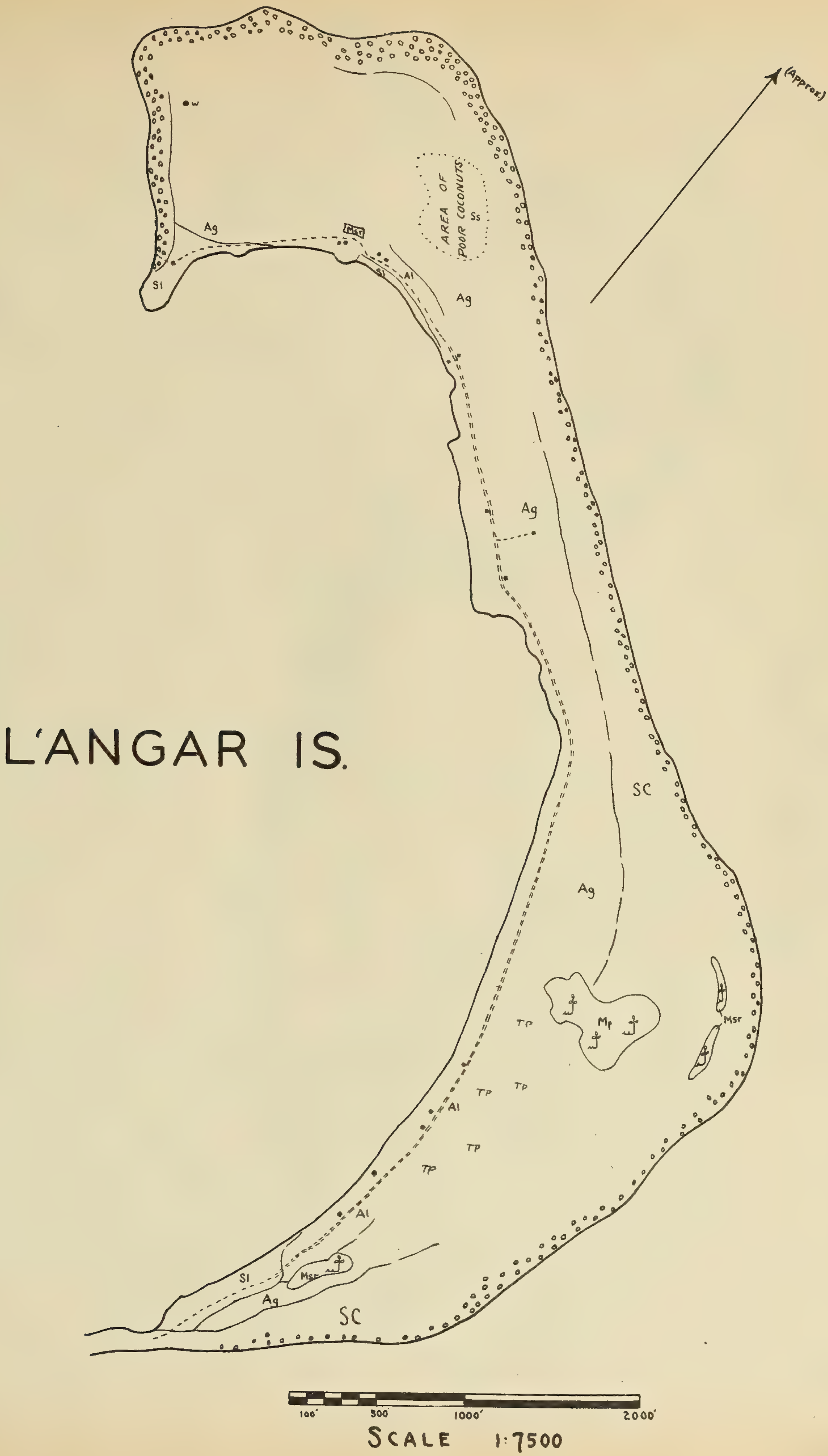

BIKONELE IS.
SC
SI
NORTH INLET
Mm
AI
TP
Ts
SALINE FLAT
(Approx)
ENËAITOK IS.
100'
500'
1000'
2000'
SCALE 1:7500

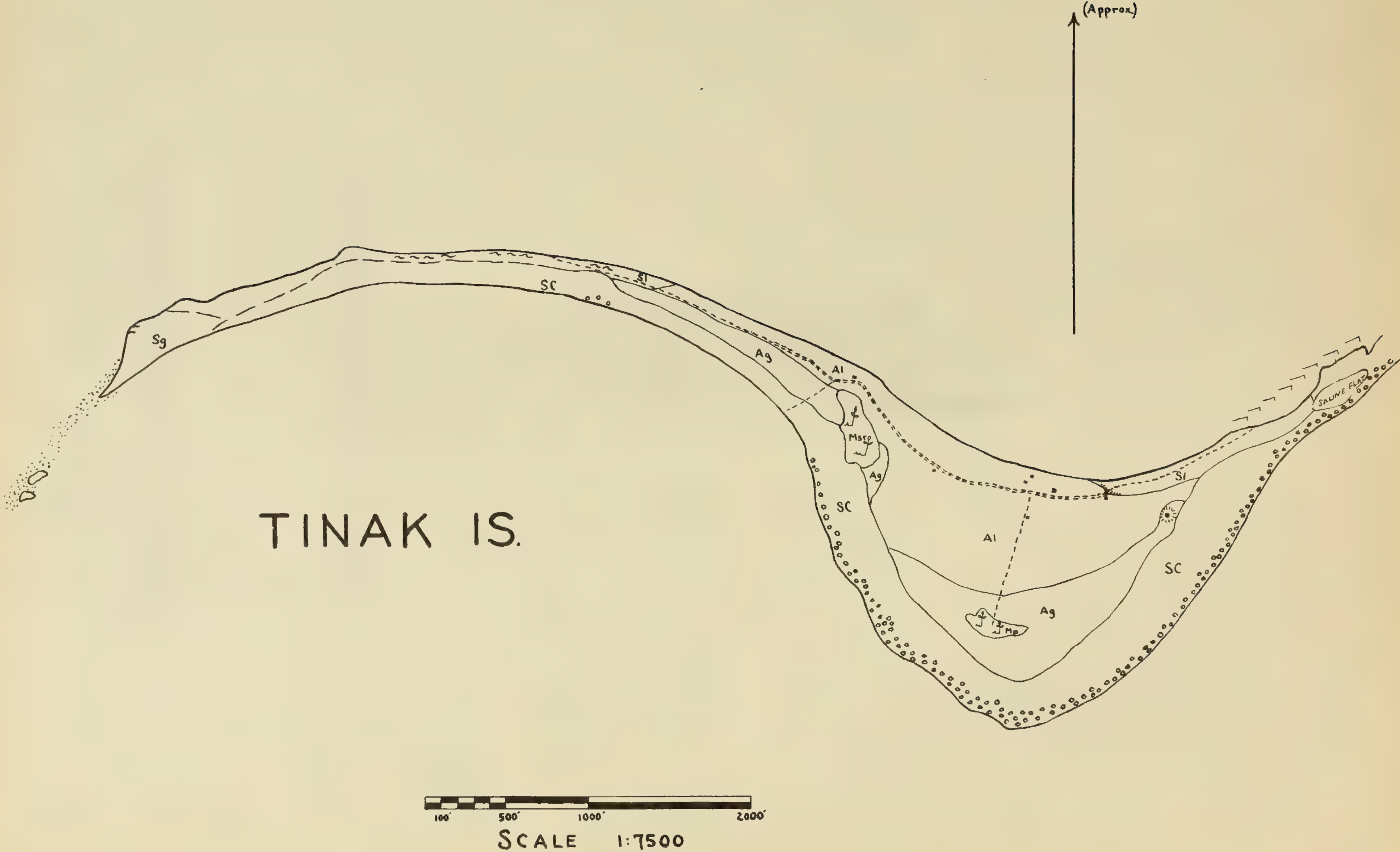
BIKAREIJ IS.


(Approx.)
SC
Al
SC
TP
Ag
w
Ag
SC
Al
w
Sl
Al
SC
Sl
Al
SC
KILANGE IS.
100'
500'
1000'
2000'
SCALE 1:7500



ÜL-EN' IS.


L'ANGAR IS.
(Approx.)
w
Ag
Msr
AREA OF POOR COCONUTS
Ss
Sl
Al
Ag
Ag
SC
Ag
Mp
Msr
TP
TP
TP
Al
TP
TP
Al
Msr
Sl
Ag
SC
100'
500'
1000'
2000'
SCALE 1:7500



(Approx)
SALINE FLAT
Sg
SC
Sl
Ag
Al
Msp
Mp
TINAK IS.
100'
500'
1000'
2000'
SCALE 1:7500

NAMWI IS.

SCALE 1: 7500

Notes on Land Conditions to Accompany Maps

ARNO ISLAND - This, the largest island on the atoll, occupies a sharp curve in the reef and extends along it in either direction. A belt of the stony complex margins the sheltered sea coast but its center seems to have been much disturbed. Areas of Shioya loamy sand occur here, the sand sometimes clearly overlying or mixed with the coarse material below. The wide interior is occupied by the Arno loamy sand and its inclusions, and a narrow belt of the Shioya loamy sand fringes the lagoon coast. The boundary of the "poor" coconut zone can be recognized at several points. The groundwater is fresh under most of the island and wells are common near the lagoon coast. A small extent of inland dune occurs on the southeast limb of the island, affording a site for one of the two graveyards on the island. Near this a stony dry channel, apparently swept by storm waters at one time, crosses the island.

The southeast tip of the island is composed of recent sands; a sandspit, covered at high tide, connects with Enen'edrik Island which is said to have been continuous with Arno Island prior to the 1918 typhoon. An indentation in the reef at this point apparently allowed breaching; it also provides the local anchorage. Enen'edrik Island follows the general pattern with rubble on the seaward side and sand along the lagoon but most of the soils appear quite immature.

BIKAREIJ ISLAND - This island may be thought of as composed of five major divisions: (1) A narrow strip of stony land fringes the entire eastern side and extends in an arc to the northeast, forming a long narrow peninsula. (a) A central lowland is composed of the saline interior sand flat in the south, the deep, mangrove-fringed inlet in the north and a low sandstone belt between. (3) A large area of Arno loamy sand makes up the center and western side of the island and (4) a very small area of this type occurs south of the western opening to the interior flat. (5) Less well developed and presumably younger Shioya soils occur between the Arno soils and the lowland.

It is evident that the history of land development has been complex. The off-shore beachrock and the exposure of the Arno soil on the very edge of the western coast suggest that considerable erosion has taken place; the southern occurrence of this soil may well have once been part of a larger area. Away from the beach, the southern part of the stony complex appears older than the northern arc and is fringed with the Arno soils. The western side of the peninsula rests on sandstone which affords footing for a few stunted Bruguiera on its corroded surface.

Limesand banks are now forming in places along the sides of the interior sand flat and an appreciable area of younger soils surround the flat, suggesting centripetal filling. A zone of soils intermediate in character between the Arno and Shioya loamy sand occurs north of the flat. Similar soils grading into the Shioya series occupy a large sector west and northwest of the north inlet. Where this sector borders the inlet is a narrow belt of recent sand deposits; here and for some little distance west the burrowing of crabs has disrupted any profile formation. Between the inlet and the southern flat is the low area described as having dark soil shallow over sandstone. It seems probable that this sandstone is continuous with that of the inlet exposure and the rock underlying the southern flat.

The small northwest island of Bikonele consists of Shioya soils and stony soils equivalent in age. A considerable quantity of pumice "pebbles" were found on the soil surface inland but their total mass is negligible.

KILANGE ISLAND - The western half of the island occupies an unique position on a reef flat that separates two narrow lagoons. Although somewhat protected by the broad reef to the north it has stony belts on both sides of the land. The northern belt ends near the lagoons but the southern one is continuous along the seaward coast. Most of the remainder of the island consists of Arno loamy sand and gravelly loamy sand, but an irregular belt of Shioya soils occurs along the northeast coast. Although not precisely located, its inland boundary coincides in part with a low (3 to 4 ft.) escarpment that merges with the seaward rampart as the land narrows to the east. Presumably the escarpment and the younger soils are the consequence of the 1905 typhoon.

Only three fresh water wells were reported on this island although many more could and may exist. One near the fork in the main trail is some 5-1/2 ft. deep in beach sands and was dry at mid-tide. Another near the western end of the wide land is "usually fresh." The third well is at the bottom of a large deep (8 to 10 ft.) depression at the inner edge of the rampart. A reported jõn swamp proved to be but a small mucky depression with two Bruguiera trees.

L'ANGAR ISLAND - The seaward coast of L'angar is fully exposed to the northeast trades and it is fringed with a high coarse rampart for its full length. Vegetation rises as a wedge with the flattened Scaevola at the rampart edge becoming a taller Scaevola-Messerschmidia scrub which, in turn, mixes with and gives way to pandanus trees. The tall pandanus, with occasional broadleaved trees, taper upward to the palms inland, the whole consisting an excellent windbreak.

For convenience the island may be considered in three sectors although the soils in all are similar, for the most part very gravelly or stony with continuous sands near the lagoon coast only. The wide northern sector is in densely overgrown coconut groves and secondary forest, and the features inland were not well located. Clearing of the groves is in progress but at no rapid rate. A tangle of Clerodendrum on moist soils west of the lagoon path provided the only truly impenetrable thicket encountered on the atoll. The phosphate deposit and area of "L'angar gravelly sandy loam" have been described. An appreciable area of Shioya sand (Profile #23), mapped from the aerial photos, is associated with a coconut malady that has "always" been present. Seedlings are yellow and the mature trees soon cease bearing, become sparsely leaved and die. A well 250 ft. inland from the rampart is reputedly the only fresh water well on the island. The bottom, some 9 ft. below the surface, was dry when seen because of sand fallen from the sides.

Inside the rampart the middle sector is made up of Arno gravelly loamy sand with a fringe of sand along the lagoon.

The large southeast sector contains several taro pits lying back of a broad dune ridge area of Arno loamy sand. The taro is said to have been killed when the pits were last flooded by salt water during the 1918 typhoon. Waves of the 1905 typhoon swept over the southern end of the island and the boundary of wave action, as recalled by the people, corresponds with that of the younger

Shioya soils. The stony complex occupies a large fraction of the sector and the remainder seems to correspond with the Arno gravelly loamy sand. This sector also contains three mangrove swamps; the easterly has a brackish pool in exposed beachrock which is another of the local marvels.

NAMWI ISLAND - Like Ül-en' Island, Namwi was seen only in a wandering tour with our hosts of the day. The island consists of four divisions: (1) About three-fourths of the western half is older land and contains the phosphate rock. (2) East of this is an extensive saline flat which is now closed off from the sea or nearly so by (3) a rampart and young gravelly land along the south and east. (4) The northern quarter or third of the island also has younger soils, chiefly Shioya gravelly sand and loamy sand.

The older land may once have extended further to the west for the marginal rampart is very narrow and highly weathered. The phosphate deposit was roughly estimated to be at least an acre in extent; at one point where the rock is exposed along the coast it shallowly overlies unaltered coral conglomerate. As noted, the dark phosphatic soil, "Namwi gravelly loamy sand", adjacent to the phosphate deposit was not distinguished from the surrounding Arno gravelly loamy sand.

The interior flat is said to be flooded 5 or 6 inches deep by high water at the bimonthly spring tides. Only the lowest parts are barren; the slight rises have a sparse growth of small Scaevola, Messerschmidia and very yellow sprouting coconuts. Along the margin are two small saline pools, the larger fringed with Sonneratia and Bruguiera.

Approximately in the center of the northern division is a shallow fresh water well. The young planted coconuts north of the well exhibit some yellowing but no severe symptoms.

TINAK ISLAND - The wide land coincides with a marked convexity of the reef. The coastal stony belt is markedly higher than the expanse of Arno soils which extend from it almost to the lagoon beach. A low dune ridge now fronts the lagoon and a cross-section from the rampart to the lagoon would show a slightly undulating surface, suggesting a series of old beach lines or ridges.

Two mangrove swamps occupy depressions. The only existing well is in an unusual natural basin, perhaps 100 ft. across, and some 8 to 9 ft. below the surrounding land surface. The "well" is a pool about 5 x 9 ft. and 3 ft. deep in reef rock or beach conglomerate. It is never dry and at high tide the fresh water rises nearly to the rock surface. Within the depression and perhaps 2 feet higher than the rim of the well is a patch of shallow mucky soil that serves as a hog wallow; water seeps into this at high tide. Elsewhere on the island two former wells are now filled.

The Shioya soils which fringe part of the lagoon coast come to border the rampart at the narrow neck of land where Tinak Island passes into Enëräen Island. An included low area of Shioya sand in young palms was flooded by high water in 1947. Further to the northeast is a small inland flat cut off between land that survived the 1905 typhoon and a rebuilt rampart.

For part of its length the gooseneck peninsula extending to the southwest shares the soil pattern of the wide island. The lower two-thirds, however, has been washed over and the soils are of younger age.

ÜL-EN' ISLAND - This island consists of a belt of stony land along the seaward coast with lagoon sands, chiefly mapped as Arno loamy sand, making up most of the remainder. The northwest tip of the island, which borders the channel separating the next islet, shows numerous narrow overlapping layers of beachrock that mark successive minor advances and now a minor retreat. Thus this edge has been relatively stable. The southeast point of the easterly bulge, however, is composed of younger soils and people recognize that it is building out, and further south the beach is said to have eroded about 12 ft. in the past 30 years. The extreme southern tip is again composed of younger sand.

The unique swampy areas were seen in a circuitous route and hence are not precisely located. The area of coconut-pandanus peat has been described. Nearby, but apparently separated from that swamp, is another containing a narrow pool, some 10 x 50 ft., surrounded by peat about 16 inches deep and mucky sands; the water is sufficiently fresh that soap can be used. West of the pool is a low area flooded at high tide; the sandy soil has a darkened surface crust but no profile development. Adjacent to this area and extending towards the higher rampart, is an immature gravelly soil with "yellow" coconuts. The syndrome resembles that observed on L'angar Island, although less severe, and suggests soil salinity. Further north a small mangrove swamp occurs in a depression in the rampart.

Four of the five wells of the island are located on the map. All are in sand near the lagoon shore and are said to be never dry or salty. Oddly, the one closest to the beach, 150 ft., apparently has the least tidal fluctuation.

APPENDIX A

SCIENTIFIC NAMES OF PLANTS REFERRED TO BY GENUS.
(According to lists kindly supplied by R. Fosberg and D. Anderson.)

Allophyllus timorensis
Artocarpus altilis
Asplenium nidus

Bruguiera conjugata

Calophyllum inophyllum
Canavalia microcarpa
" sericea
Centella asiatica
Clerodendrum inerme
Colocasia esculenta
Cordia subcordata
Cyrtosperma chamissonis

Eleusine indica

Fimbristylis cymosa
Guettarda speciosa
Intsia bijuga
Ixora casei

Lepturus repens
Lumnitzera littorea

Messerschmidia (Tournefortia) argentea
Morinda citrifolia

Nephrolepis acutifolia

Ochrosia oppositifolia
Osplismenus compositus

Pandanus tectorius
Pemphis acidula
Pipturus argenteus
Pisonia grandis
Polypodium scolopendria
Premna integrifolia

Scaevola frutescens
Sonneratia caseolaris
Suriana maritima

Tacca leontopetaloides
Terminalia samoensis
Thuarea involuta
Triumfetta procumbens

Vigna marina

Wedelia biflora

APPENDIX B

ABRIDGED DESCRIPTIONS OF PROFILES SAMPLED FOR CHEMICAL ANALYSES (Table II)
(See also descriptions of numbered profiles in text.)

Profile #23 - Arno loamy sand. From area of poor coconuts, interior of Arno Island:

0 - 6"	Black (10 YR 2/1) granular organic loamy sand or sandy loam, heavily flecked with limesand particles.
6 - 8"	Rapid transition from very dark gray to light gray limesands.
8 - 48"+	Single grained loamy sand containing some coarser forams, very pale brown (10 YR 8/3) becoming pinkish white (7.5 YR 9/2) at depth. Soil moist at 30-36" but no water encountered.

Profile #29 - Arno loamy sand. Wide portion of Jab'u (Ine Is.).

Surface	Two-thirds covered with decomposing breadfruit and Guettarda leaves.
0 - 8"	Very dark gray (10 YR 3/1), highly organic, somewhat plastic sandy loam or loamy sand containing some gravel and small stones. Earthworms present.
8 - 12"	Transitional.
12 - 36"+	Single grained loamy coarse sand, pinkish white (7.5 YR 9/2) becoming white (5 YR 9/1), containing some gravel and small stones.

Profile #6 - Arno gravelly loamy sand. Ine Island, southeast of village.

0 - 1/4"	Incomplete cover of pandanus and coconut leaflets, etc.
0 - 15"	Very dark gray (10 YR 3/1 or 2.5/1), coarsely granular, highly organic gravelly loam becoming sandier near the bottom. Earthworms abundant. Much of the large content of gravel is rotten and can be crumbled.
15 - 18"	Transitional.
18 - 56"+	Pinkish white (7.5 YR 8/2), single grained limesands containing some gravel. Slight localized cementation around coconut root at 36" but no general cementation.

Profile #4 - Moderately well drained associate of the Arno series developed over a buried profile. Ine Island, southeast of village.

0 - 8-12"	Very gravelly, dark gray (10 YR 4/1), somewhat plastic organic loam flecked with light sand grains. Earthworms abundant. Gradually changing to

8-12 - 16-20" Heterogenous transitional zone consisting of mixed limesand or a pure foram sand flecked with black from decaying coconut roots and with tongues of organic matter penetrating from above. Earthworms still abundant in this horizon.

16-20 - 28" White (5 YR 8/1) loamy sand.

28 - 35" Transitional. The loamy sand becoming grayer and slightly cemented.

35 - 58"+ Gray (10 YR 5/1) loamy sand heavily flecked with white sand grains. Many roots occur in this horizon and large stones are found near the bottom of the profile. Groundwater level at 58" near the high tide peak.

Profile #14 - Shioya sand. Area of poor coconuts in interior of L'angar Island.

0 - 10" Pinkish gray (7.5 YR 7/2) single grained loamy sand.

10 - 36"+ Pinkish white beachsand appearing quite fresh and unweathered.

Profile #27 - Shioya sand with surface deposit. Narrow land revegetated after the 1918 typhoon, Jab'u (Ine Is.).

+4" - 0 Overburden of sand washed from dune above. White (10 YR 8/1) with some varicolored fragments, single-grained, already well penetrated by small coconut roots.

0 - 6" Light gray (7.5 YR 7/1) limesand mixed with some coarse gravel, densely penetrated by coconut roots. No worms present. Becoming somewhat lighter and coarser without the gravel at the bottom of the horizon.

6 - 70"+ Gradual transition from above to pinkish white (7.5 YR 9/2) limesand somewhat spotted with decaying coconut roots in the surface six inches and locally below. Coconut roots common to at least 36". Groundwater level at 42 inches after heavy rains.

Profile #18 - Mangrove peat. Tinak Island.

0 - 8" Fibrous woody peat from Bruguiera. Dark reddish brown (5 YR 2/2) crumbs mixed with a large mass of small rootlets. Fine coral fragments present.

8 - 16" Similar but with fewer roots and more coral fragments. Groundwater at 15".

Profile #26 - Coconut-pandanus peat. Ūl-en' Island.

0 - 26" Very fibrous woody peat consisting of dark organic crumbs mixed with a mass of root fragments, many of them hollow. Water level at 8" below surface when sampled, 3-8" above the next morning after heavy rains.

APPENDIX C

EFFECTS OF MANGROVE MUCK FROM BIKAREIJ ISLAND

The following is an account of the reputed effect of the muck on human skin as given by several people on this island:

At high water during the spring tides, schools of a desirable fish, "Beleo", enter the inlet and can be prevented from leaving as the water falls by a stone weir. On special occasions, formerly designated by the King, this area is "fished." By custom the entire village is required to go as a group. At low water the men wade about in the muck, churning it until the mud "soaks up" the surface layer of water. Thereupon the fish stick their heads out of the ooze and are caught or speared, the catch being very large, "more than a thousand" by Marshallese arithmetic.

If a man remains in this mud for as much as "three hours" his body below the point of immersion will swell greatly. For four days he will suffer headache, fever, loss of appetite, etc. On the fifth day these symptoms subside and the small blisters on the skin, resembling those of heat rash, break. The old skin can be peeled off "like a glove," exposing new epidermis beneath. An exposure of two hours has some effect so the general rule has been to limit exposure to one hour. (All time intervals as given by Kieotak.)

The details of this malady and its occurrence were clear and consistent in the accounts given by different people. A Japanese who visited the island to investigate this phenomena gave no explanation and only suggested swabbing with Lysol solution after exposure. It is clear that prolonged exposure is required for injury and that this is superficial. The cause can only be conjectured but there are two likely agents: (1) sulphites or sulphides in the alkaline slurry and (2) (suggested by Dr. Steven Kliman) tannins derived from the mangroves.

In addition to its external effects the mud is reputedly toxic if it accidentally enters the mouth when one is tired. A small amount (= "one finger joint") is sufficient to cause dizziness and unconsciousness. Two persons are said to have been lost in the mud after having been so overcome. Wading waist deep in the viscous slurry is a very fatiguing task, however, and it is possible that these latter effects might be due to over exertion.

APPENDIX D

DISPOSITION OF PLANT COLLECTIONS

Since Mr. Donald Anderson had collected the higher plants of the atoll just previous to the visit of our party, my collection of these was largely for orientation. Fertile material of Dryopteris goggilodus and Oplismenus compositus and two additional plants, Nasturtium sarmentosum and Eleocharis geniculata believed not collected by Anderson have been placed with his collection; the remainder of my partial collection will go to the herbarium of the Botany Department and the Bailey Hortorium at Cornell.

The few lichens were sent to Dr. Joyce H. Jones of the University of Michigan Herbarium who has identified them as follows:

1044 - Pannaria mariana (Fries) Müll. Arg.

1065 - Physcia picta (Sw.) Nyl.

1081 - no spores found

1119 - gray wider lobes - Coccocarpia cronia var. isidiosa (Müll.Agr.) Vainio, greenish gray - Physcia integrata var. sorediosa Vainio

1120 - Parmelia corraloidea (Mey. & Flot.) Vainio

1145 - crustose - no spores found

1150 - Physcia picta (Sw.) Nyl.
a, b and c. are the same

1151 - found no fruiting bodies

1152 - Coccocarpia cronia var. isidiosa (Müll. Arg.) Vainio

1157 - Leptogium sp. - found no fruiting bodies.

A few collections of terrestrial algae were sent to Dr. R. H. Thompson, Department of Botany, University of Kansas. A number of fungi were turned over to Dr. Clark Rogersen, Department of Botany and Plant Pathology who has sent the Basidiomycetes to Dr. Don Rogers of N. Y. Botanical Garden. The mosses and hepatics were identified by Professor A. L. Andrews of Cornell.

MOSSES AND HEPATICS FROM ARNO ATOLL, MARSHALL IS., 1950

Mosses

1039	Calymperes thyridioides Broth.
1041(a)	Ptychocoleus pycnocladus (Tayl.) Steph.
1042	Ectropothecium sandwichense (Hook. & Arn.) Mitt.
1043	Leucophanes smaragdinium (Mitt.) Par.
1115	Trichosteleum hamatum (Dozy & Molk.) Jaeg.
1116	Ectropothecium sandwichense (Hook. & Arn.) Mitt.
1154(a)	Meiothecium papillosum (Broth.) Broth.

Hepatics

1040	Riccardia fuscescens (Steph.)__?__
1041(b)	Lejeunea sp., (Subgenus Cheilolejeunea)
1154(b)	Lopholejeunea subfusca (Nees) Steph.
1155(a)	Drepanolejeunea Riddleana Steph.
1155(b)	Lejeunea sp.

The above workers will retain material for their own herbaria and in accordance with the National Academy of Science agreement duplicate collections will be sent to the National Museum. Any additional material will go to the Bishop Museum.

ATOLL RESEARCH BULLETIN

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6. The Agriculture of Arno Atoll, Marshall Islands

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THE AGRICULTURE OF ARNO ATOLL,

MARSHALL ISLANDS

C O N T E N T S

To the ecologically minded the low islands appear as a unique habitat for man, an environment not harsh but marked by lack of diversity and, in many respects, by monotony. Here is a climate so equable that the average temperature for any month departs not more than a degree from the yearly mean, a land restricted in size and relief, dominated by the sea, and made up almost entirely of one material -- calcium carbonate. Upon this are soils uniformly calcareous and differing chiefly in texture and degree of maturity. Distance, soils and the sea salt have sharply restricted the number of land dwelling plants and animals, and so limited man's choice of foods and materials.

THE GENERAL AGRICULTURAL SCENE

Physical Setting

The climate, hydrology and soils of Arno Atoll are described in other reports but may be summarized as background thus: The mean annual temperature presumably is almost identical with that of Jaluit, that is 80° F., with monthly means deviating about $\pm$ 1°. Rainfall is some 120 inches, possibly higher, rather well distributed but with a tendency for a dry period between January and March. High humidity and high degree of cloud coverage augments the effects of rainfall, whereas the more or less constant winds, coarse textured soils and short term (e.g. one week) periods of dry weather sometimes lead to a moisture stress in plants. Since the ground water commonly occurs three to six feet below the soil surface its salinity is a major factor controlling the distribution of deep rooted vegetation. Shallow rooted plants, however, draw upon the rainwater held in the soil.

Agriculture

Like other aspects of the Atoll, the agriculture is marked by simplicity. There is no sharp separation between agriculture and non-agricultural plants and, to Western eyes, culture is a somewhat casual affair at best. At first glance the coconut dominates the agriculture as it does the landscape but there are other components to both. A shrub belt lines the seaward shores and takes possession of lands too salty or too new for other vegetation. In the interiors of the wider islands are breadfruit, sometimes in groves or often scattered, with a variety of other plants beneath. In this zone, too, are the old excavations made to provide suitable growing conditions for taro for here the groundwater is largely free of salt. Mixed with the breadfruit are tall coconut palms and these form extensive groves around the zone and along the narrow lands adjoining.

Various writers have described the agriculture of the atolls as consisting of tree and root crops -- coconuts, breadfruit, pandanus and bananas, together with taro and Polynesian arrowroot. In a general sense this is true but on Arno the taro has lost most of its former importance. Sweet potatoes are a rarity and other tropical root crops absent. Further, poultry and, to a limited extent, pigs are part of the casual husbandry. Fish and seafoods provide the protein the land does not. Over the years copra traders, missionaries and former German and Japanese residents have introduced a large number of plants but of these the weeds and ornamentals have been most persistent.

Although the introduced plants have not greatly influenced the basic agriculture, the prolonged emphasis on copra production has. Well before the beginning of "German times," traders made copra a commodity of value; under German and, later, Japanese administrations people were "encouraged"

to continually increase the area of coconuts. Ultimately this extension eliminated the native forest that once covered the unused lands and reduced the number of breadfruit and pandanus.

Other changes occurred during the early period of missionary activity and German contact: Old men now living say that the population diminished greatly then, although this is unsupported by other evidence. Certainly a population shift occurred, with people moving to lagoon shore and abandoning the less desirable house sites on the seaside and island center. The culture of taro, once a staple, diminished, very probably because the introduced hogs became very abundant and devastated the taro pits. The copra brought goods from the outside world and these gradually became essentials. Under the influence of trade, outside authority, and religion the established culture changed, and the transition from old ways to new is still in progress.

PLANTS AND THEIR UTILIZATION

Coconut, "Ni"

Although waving palms are almost synonymous with atolls, the extensive coconut groves are as artificial as orchards and will not persist without man's care. Under the influence of the copra trade, "native" vegetation gave way to palm plantations wherever growth conditions were suitable; much of this occurred within the memory of men still living.

Culture

There has been little varietal selection and most of the palms bear nuts of mediocre size, although the people recognize differences such as nut color and edibility of the mature meat. Under Japanese instruction "diseased" trees -- presumably scale infested -- were cut, possibly reducing the number of susceptibles. A large fruited coconut has been introduced and is found in small numbers but there seems to be no concerted attempt to

increase this variety.

The culture of the coconut is simple but continuous. Planting consists of removing a square of sod or the loose rocks if necessary and placing the sprouting nut. The large amount of stored material in the nut gives rise to a large seedling and even in deep rubble the roots reach down to establish contact with soil moisture. Competing vegetation is kept down and trees are said to reach bearing age in about five years. Present planting is largely a matter of filling in occasional openings but in several areas the palms are over-mature and replacements should be considered. The coconut, of course, tolerates considerable salt, possibly even benefiting from it, and palms have been planted over the entire salinity range, from the wide island interiors to areas too salty for normal growth.

The groves require continual weeding for a large variety of woody species soon spring up beneath the palms and if unchecked compete with them, as well as making nut gathering almost impossible. Near the coasts and on narrow lands Scaevola, Messerschmidia, Guettarda, Ochrosia and "wild" pandanus are aggressive invaders whereas inland Allophyllus, Morinda, Pipturus, Pandanus, as well as some of the above fill in beneath the palms. In plantations left unharvested, particularly those of the interiors, sprouting nuts soon make a solid mass of undergrowth. Periodic cutting is the only means of controlling this vegetation. Once well cleared an area can readily be maintained but when abandoned for a long period, as many plantations were in the later stages of the war, strenuous efforts are required. Often the coarse herbaceous vegetation, such as Wedelia, is also cleared. Usually the brush is burned, together with the fallen fronds. Sometimes the piles for burning are placed over stumps or against undesirable trees so fire supplements the machete. Quite frequently, however, palms and

other useful trees are scarred by careless burning. When the emptied husks and fallen fronds are heaped together burning is often incomplete and the lightly charred heaps decay naturally. Except for these, the signs of fire disappear rapidly; woody and herbaceous sprouts soon mantle the soil and the profound effects of the clearing may go largely unappreciated by the casual observer.

Copra Production

The major export product, of course, is copra. According to Lajiblok, who has largely transported the crop, the monthly production for the atoll is about 53 tons but sometimes drops to only 30-40 tons. These figures should be reliable but have not been otherwise verified. So far as could be learned the variation in production is not seasonal. At the current price of $80 per ton the atoll income from outside sources is much greater than might at first appear.

Supposing the average monthly production to be 50 tons and estimating that this is produced from 2,000 acres (roughly 5/8 of the total atoll area) of coconuts worked for copra, the average yield would then be 0.3 tons per acre per year, not a high figure. Further, if we assume that 2,500 acres is the maximum average available for palm groves and 0.5 tons per acre per year is the maximum average yield likely to be obtained, we find that an annual production of 1,200-1,300 tons of copra is about the maximum expected output of the entire atoll under foreseeable cultural practices.

Copra production is slow and tedious business but less so when made a group activity as it often is. The fallen nuts are thrown into heaps, often using a sharp tipped "pickup stick," and husked on a flat pointed husking stake. This is of any hard wood, sometimes shod with a Japanese-made hollow steel tip, and set firmly in the ground. Later the nut is

cracked into pieces and the meat pried from the shell. All the copra manufacture observed involved artificial drying, at least in the initial stages. The shells are excellent charcoal source and this is somewhat inefficiently made by burning off the volatile matter, often in an oil drum. The charcoal is then burned beneath the rack containing the thinly spread coconut meat, the entire rack being more or less closed to conserve heat and regulate the draft to the fire. With skill, little scorching of the copra occurs. Further drying is generally by exposures to the sun, either in racks or on mats, etc. spread on the ground. The sacked copra is transported to concentration points for later shipment.

There is a wide variation in the efficiency with which different individuals produce copra but the average is low. Some of the measures for improvement are obvious: (1) As a rough estimate, perhaps one-fourth of the area now in bearing age palms is too thickly vegetated for effective nut collection. Examples of this may be seen on L'angar, Bikareij and the western portion of Ine Island as well as on Ül-en' and Namwi Islands where reclearing is now going on. On an additional area the vegetation is dense enough to interfere to some degree. The population shifts and disturbances caused by the war are at least in part responsible for this but reclamation has been slow. The pattern of land "ownership" also leads to neglect of the areas remote from the major "operator." Bringing all suitable areas into normal production could easily increase the atoll's copra output by one-third. (2) Although the better producers are aware that sprouted nuts yield less copra, the majority seem untroubled by a high percentage of sprouting. The succulent tissue filling the cavity of the sprouting nut, "iu," is eaten but it is an expensive food in terms of copra. The mass and respiration of the external aprout itself represent sheer waste of copra without any reduction in the amount of labor

necessary to extract the remainder. Periodic gathering of the nuts and storage on sheltered racks to allow absorption of the milk and prevent sprouting is a practice long recommended elsewhere. By this means alone an increase of perhaps 10% in copra could be obtained without proportionate increase in labor. (3) A few producers have drying sheds, i.e., roofed buildings housing the dry racks, but the majority get along with cruder and often impromptu arrangements. It is undoubtedly effective to spread copra on the mat in the sun for curing or re-drying but chickens, pigs and sudden showers are attendant hazards. Widespread adoption of the best drying practice already in use in the atoll would not increase the production greatly but would reduce the labor involved and contribute to a higher quality product.

The above comments on increasing production concern only practices already known to the Arnoese and accepted, in large part, by some of them.

Uses as Food

The mature meat and dried copra are less used for food than might be thought. Since the fruiting occurs throughout the year the oily nut is an excellent emergency food and apparently has its greatest use in between the pandanus and breadfruit season. In many cases copra for eating is made of nuts from particular trees, apparently selected for tenderness and sweetness of the flesh. The "iu" from the sprouting nut cavity is eaten out of the hand and also baked; it is eaten in quantity when copra is being made. Coconut "cream" squeezed from the grated mature nut is widely used in cooking, particularly of the more elaborate dishes, but is of only minor importance in terms of average consumption per person. Although methods of extracting oil from copra are known, they are tedious and it appears that very little is made, despite the general demand for cooking fats and hair pomade.

The immature nuts are used in quantity for drinking, and the soft sweet

flesh is commonly eaten as well. It would be difficult to fairly estimate average consumption over the atoll, for drinking nuts are usually proffered the visitor as routine courtesy; furthermore, the use away from the villages, particularly by men working in the groves, is greater than within the populated areas. Nevertheless, the total is great and perhaps is limited chiefly by the necessity of climbing the tree and of husking the nuts if they are to be carried.

Another widely known beverage from the coconut is the palm sap, obtained from the "flower stalk." Before the flowers emerge from the large elongate bud the tip is cut off and the juice flow observed. If satisfactory the leafy covering (spathe) is wrapped with twine to prevent opening except near the tip where it is cut away, exposing the spadix within. This is also wrapped and bent downward into a container; the sap flows from the cut surface, which is renewed by cutting each time the sap is collected. To facilitate collection, palms regularly "tapped" are notched with shallow steps the length of the trunk. On Arno the fresh sugary liquid, "jekara," is drunk fresh or occasionally boiled down to a syrup having a characteristic flavor. In the latter form it can be kept for long periods, by occasionally reheating, and serves as a sweetening. According to Spoehr, on Majuro jekara is consumed in quantity but casual observations on Arno suggest that the average consumption here is quite low. The sap ferments very rapidly and, of course, provides one of the principal alcoholic drinks throughout the range of the palm. The Arnoese, although they may jest about this product "jemanin," are reluctant to concede that it might be produced by anyone on the atoll. This is understandable, if not altogether credible, for both the missionary influence and the Mandate terms have worked against demon rum.

Other Uses

The meat from both copra and drinking nuts is often fed to chickens and pigs, either as scrap or as supplementary feeds. Surplus "iu" from copra making is also fed to pigs.

Both the husks and the large leaves of the coconut rate as major products. The dried husks, convenient in size and in abundance, are the major fuel particularly in the well settled places or where the groves are kept free of other vegetation. The husks are also the source of twine (sennet) and rope. The long vascular fibers are freed by retting the husks for at least one or two months. If let stand for only the minimum time the husks must be pounded to free the fibers whereas with longer retting the fibers can be rubbed free of the decomposed husks in seawater. The retting apparently takes place satisfactorily in salt, brackish, or fresh water for all three are used. Husks may be buried near the high tide level on stable beaches usually along the lagoon side. Inland are retting pits, "tou," dug below the groundwater level, either fresh or brackish. Often the tou is located in a natural depression and it may be only a muddy spot in an old taro pit or brackish swamp although, according to legend, a tou on Ül-en' Island was conveniently excavated by a star.

The washed and dried fiber or coir is made into a two strand twine, sennet. Each strand is formed endlessly by repeatedly adding groups (15 to 25) of the long parallel fibers to its untwisted end, each addition and its juncture being twisted by rolling between palm and thigh. The additions are made alternately to the two strands and between additions the strands in turn are rolled together to form the twine. The product is a tough cord that may be used for lashing, as on canoes and houses, or braided into a strong and durable rope.

The palm leaves likewise provide a fiber although of much less importance than sennet. The epidermal layers of the flat upper surface of the frond midrib are stripped free of the coarse tissues below to give a strong, somewhat brittle, strap several feet long. This is chiefly used on the spot, rather than as a permanent rope, but finds considerable use. Epidermis peeled from the individual leaflets twists into long flexible fibers used chiefly for fine weaving.

The flat leaflets of the frond are readily woven and from a palm leaf an Arno resident of any age can usually produce a basket of almost any proportions. The leaflets are left attached to the portion of the midrib which serves as a rim of the basket. Although considered much inferior to the pandanus, coconut fronds and stripped leaflets can be quickly woven into matting or panels for temporary house construction. The dry matured midribs are stiff and are sometimes used as rafters in house construction. The trunk is only occasionally used in house construction. It was once common to chop a cavity in the palm base to catch water flowing down the stem. This "emmak" was further enlarged by decay and ultimately contributed to the destruction of the tree. Although these cavities are still found on older palms they have long since been supplanted by cisterns and oil drums. The juice squeezed from the green husks is considered of value in reducing the irritating properties (presumably caused by calcium oxalate crystals) in the prepared roots of Alocasia. If the juice is indeed effective this cannot be due to its acidity, for samples tested were above pH 5.5.

<u>Factors Affecting Production</u>

As mentioned, the red coconut scale is present as well as a leaf spot but we saw no severe infestations of either. More serious pests, such as the rhinoceros beetle, are absent. Effective quarantines would minimize the likelihood of introducing major pests found elsewhere in the Pacific, but it is

doubtful that native shipping can ever be well inspected.

Areas of "poor" coconuts are found on the islands of Namwi, Ül-en', L'angar and Arno. On Ül-en' a portion of the affected area is adjacent to an inland salty pool, and is said to be flooded by the highest tides. Excessive salinity also probably accounts for similar symptoms observed on the younger portions of Namwi. On L'angar a malady locally attributed to the presence of demons causes yellowing, poor fruiting and early mortality on a tract of perhaps five acres in the interior. The presence of excessive salinity is perhaps as likely as that of demons but the soil samples have not yet been analyzed for either. In traveling, small areas of yellow palm foliage have been noticed on other islands but, on the whole, salinity is only a minor problem in the coconut groves and certainly one not readily remedied.

A tract of several acres in the interior of Arno Island is characterized by early barrenness and gradual death of the palms. According to the Headman of the village this condition has always existed in the same area, the coconuts being maintained only by continuous planting. There are no visible evidences of insects or pathogens and the characteristic leaf symptoms differ from those observed in saline areas. Breadfruit trees growing among the dying palms appear to be unaffected. The appearance and depth of sandy soils do not differ from adjacent areas where palms are normal but the long persistence of the malady within definite boundaries suggests some soil relationship. These soils are relatively removed from the shore and seem to be among the oldest on the atoll; nutrient deficiency is at least a possibility and forthcoming analyses of soil samples may help clarify this problem. The exact acreage affected cannot be well estimated because of interspersions of breadfruit groves and secondary forest; these, however, are said to be so abundant because of failure of the palms. The loss in coconut production is to some degree compensated for by

growth of such other species and the simplest solution is to give up trying to grow coconuts within this area. Attempts to discover the cause of the malady would be worthwhile, however, for it may well be found on other atolls, and its amelioration may not prove difficult.

Some comments on copra production have already been made. A further need is a replacement program to eliminate older trees past the peak of bearing. If varieties superior to those now in use can be found, their establishment would logically be coupled with such a replacement program. The introduction of large fruited strains might help reduce the labor involved in copra manufacture even though no yield increase resulted. The possibility of finding higher yielding varieties is worth exploring fully but the limitations of the atoll soils and their dissimilarity from those of most commercial planting areas should be borne in mind.

Breadfruit, "Mā"

Wherever its origin, the breadfruit, like the coconut, is well adapted to the atoll habitat. The breadfruit is characteristic of the interiors of the wider lands although it may grow almost to the beach when conditions are suitable. It is the common tree along walks and settled areas. Its distribution is almost certainly related to the salinity of the groundwater (see report of Hydrologist) and it is not found in the narrow lands or obviously salty areas.

Culture

At least six well-recognized varieties are grown on this atoll. Fruit characteristics seem to be most dependable criteria for identification although leaf form is indicative except for occasional inconsistencies. No differences in tree form are associated with variety, according to the Arnoese, and there are only minor differences in season of fruiting. Two or three varieties have seeds; the remainder are seedless. Examples of varieties with seeds are the Mātata,

which has leaves cut almost to the midribs, and the Mājwan (Mijwan) with large, 3-5 lobed leaves, the lobes limited to the distal half of the leaves. Another type of the Mājwan has entire leaves. The Bātaktak is the preferred seedless variety with a large, solid fruit. It has large 5-lobed leaves, the lower lobes extending for perhaps two-thirds the length of the leaf. By contrast, the Mākinono is named for the resemblance of the 7-9 narrowly lobed leaves to those of the kino fern. Its fruit is globose and regular, turning light yellow when ready.

Around the older trees young breadfruit arise from seeds and root suckers so replacement planting is often unnecessary. Trees blown over usually sprout vigorously from the root crown and stem. The idea of vegetative reproduction is understood and suckers from desirable varieties are taken to establish new trees. Despite this, varieties said to be less desirable are still abundant.

The culture of the breadfruit is even more simple than that of the coconut. Vegetation directly competing with the young trees is cut although the plant tolerates a fair amount of side shade from taller trees and is often started in small openings. The tree grows rapidly, particularly if a sprout from an existing root system, and its own dense shade soon eliminates much of the vegetation below. Thereafter no care is given except as the expanding crown comes into competition with less desirable trees which may, in the course of time, be removed.

Tree form is greatly influenced by density. In the open or with continuous removal of side competition breadfruit tends to branch low and form a massive crown. When crowded in youth the lower branches shade off and the tree has a smaller, often ragged crown and a tall columnar trunk. Such differences in older trees have interpretive value in revealing growth conditions at an

earlier period.

The peak of the breadfruit season is from May to July but the trees continue to bear in decreasing amounts until December. Individual trees vary in duration of yield but there is little varietal difference. As might be expected the large crowned trees tend to be more fruitful but are not necessarily more easily harvested. To "pick" the fruit a man climbs the tree, often using a rope to reach the first branch. Most of the fruit is reached with a picking pole some 20 ft. long, having a Y-shaped end to thrust against the fruit. With it, or by hand, the fruit is detached and falls to the ground. In narrow crowned trees most of the fruit is readily seen and can be reached with the pole from the central trunk, whereas in large spreading trees much of the fruit can be reached only from more hazardous positions midway out on the larger limbs. The fruits suffer much less than might be expected from the 30 to 60 foot fall but some are marred by exudation of the gummy latex into bruised areas. Needless to say, when the trees overhanging walks are being picked the local traffic either halts or detours.

Used as Food

During the season of fruiting breadfruit is the single most important food on the atoll. For most purposes the green fruit is preferred and the most common means of preparation, particularly for the preferred Bātaktak variety, is baking over charcoal. After cooking the pineapple-sized fruit is scraped clean and is then ready to be eaten or carried. The fruit may be cooked in a large number of other ways, suggesting the use of both potatoes and bread. Ripe breadfruit is somewhat sweeter and has a definite fruity taste; it is prepared somewhat as a delicacy. The rather large (3/4 - 1") seeds of the seeded forms are eaten with the cooked fruit but are not usually gathered for that purpose when freed by natural decay of the fruit.

Although the breadfruit is perishable it is preserved by methods analogous to ensiling. The green latex-containing epidermis is scraped away, the fruit sliced and soaked in seawater. Upon removal the material is packed tightly into leaf-lined pits and covered with leaves which are changed regularly. Before use the starchy paste is thoroughly washed in seawater to remove the fermented taste, considered undesirable by the Marshallese. Although the method produces an acceptable foodstuff and is recognized as a means for preparing for the lean months before the next breadfruit season, it does not seem that very large quantities are stored in this way.

Other Uses

Near the houses the freshly fallen breadfruit leaves are often gathered for wrapping fish, breadfruit paste, etc., prior to baking. The milky latex that flows abundantly from bark wounds was once used, after hardening, as calking for canoes; it is now used only when prepared materials are not available. The latex can also serve as a bird lime although this is of little consequence to present-day people. The wood of the breadfruit is moderately soft, durable and withstands alternate wetting and drying. Further, it occurs in long pieces of relatively large diameter and so is the universal choice for canoe construction. Smaller diameter pieces and, occasionally, hand worked timbers are used for house construction.

Factors Affecting Production

So far as observed the tree itself is free of major pests. Only occasional instances of heart rot were observed and the few dead trees seen were all past maturity. A malady affecting the fruit, resulting in a partial decay and premature drop, was reported on Arno, Ine, and L'angar Islands, but not on Ül-en'. According to Kotiel of Arno and Loban of L'angar, the malady was first observed about 1948 and affected a large number of fruits during the

following two years, becoming less severe in 1950. Examination of fallen fruit shows a portion of the surface blackened with rot extending inward. When the stem or the central axis is weakened the fruit falls prematurely. The nature of this malady and its seriousness require a thorough investigation (see report of the Entomologist).

As mentioned, the distribution of breadfruit is certainly related to ground water salinity although little is actually known concerning depth of rooting. Generally the tree reaches maximum development in the sheltered interior of wider islands but large open-grown trees are found in settled areas and occasionally very close to the beaches. It is evident that salinity in the rooting zone will be affected by permeability of the underlying materials, depth of soil above the ground water and conditions controlling the outward flow of ground water, as well as by mere distance from the beach. In some areas (e.g. the southern part of Bikareij village) the trees reach fair diameters but appear stunted in height and show dead wood in the tops. Their appearance and location suggest salinity as a cause, perhaps acting through recurring injury or root restriction during dry periods rather than by continuous exposure. In this connection breadfruit on the lower rainfall islands of the northern Marshalls is said to be much shorter than in the south. Salinity problems are generally beyond man's control and affected areas can only be avoided.

The quantity of breadfruit in the atoll appears to be more than adequate for average needs during the seasonal peak, although additional vigorous trees would increase the late season supply. In addition to establishing more trees, replacement of less desirable varieties with better, and judicious thinning in crowded groves, as on Arno Island, would augment production. Young trees not required for food production, however, might well be kept in somewhat crowded stands to improve stem form for later utilization.

In any comprehensive work with breadfruit selection for fruit characteristics and season of fruiting would be as important as for total productivity. Introduction of other varieties of Artocarpus altilis, as well as other species of the genus is certainly worth trying. The present method of harvesting the fruit appears satisfactory to all concerned but small experiments in pruning young trees to a low spreading shape would not be altogether out of place. Artificial fertilization will probably be out of the question for a long time except with locally available phosphate.

As is true also for other crop plants, the native culture of the breadfruit includes no fertilization practice. Among the store of local medicine are at least three procedures for increasing the yield of breadfruit but, whatever their effectiveness, the materials used are in much too small quantities to affect soil fertility. The course of civilization has apparently eliminated one threat to the breadfruit for black magic is no longer considered an effective means of destroying the tree, although our informant believed it was successful in the past.

Pandanus, "Bōp"

Culture

Anderson considered all of the pandanus on the atoll to be varietal selections of P. tectorius and listed 16 varieties. Of these one, Bōp in Kabilin̄, with white margined leaves was reputedly introduced from the Carolines (Kabilin̄) and is found only as an ornamental. Another, Edrwan, apparently includes the straight-stemmed, small-fruited "wild" types rather than being a definite variety. The remainder are recognized as established varieties, distinguished principally by fruit characteristics which the writer never mastered. Fruit shape and, particularly, the shape of the nutlets and their aggregates seem to be the significant features. Fruit size, other than Edrwan

is not; the largest fruit is borne on young trees. Likewise leaf characteristics change with age. Certain varieties, such as Anberia and Joibeb, are recognized as outstanding for eating out of hand but our informants seemed uncertain about other specific choices among the varieties.

The pandanus season begins in October, attains its peak in November and December, and falls off after January but a few fruits mature throughout the year. There seem to be no certain varietal differences in time of maturity. The varieties are reproduced vegetatively, using the long prop roots as stock. Seedling clusters from fallen or discarded nuts are common weeds in coconut groves. These volunteer pandanus are hacked down in clearing groves although larger straight stemmed trees are often left. Plantings of the pandanus are scattered as isolated trees and small groups along paths and near houses as well as on the lagoon shore or dune, as in the interior.

The pandanus seem to have a considerable tolerance for salinity and the wild form is often found in abundance on the beach rampart of the windward coasts between the Scaevola-Messerschmidia scrub and the coconuts. The wild forms are also common on dunes and back of sandy shores bordering the lagoon but here as elsewhere they are often replaced with cultivated varieties. Culture of the latter consists of removing competing vegetation.

Uses as Food

Among the more colorful sights of the atoll are brown-faced youngsters chewing on chrome-yellow pandanus segments. In the uncooked form these serve as does sugar cane elsewhere in the tropics, albeit more flavorful. Upon baking the flavor tends to change but the non-fibrous portion is more readily extracted. This somewhat mucilaginous material is also scraped free and dried; in this form it can be stored without spoilage as an emergency food. The small nuts can be extracted and cracked for the contents although this is not a very

rewarding task. The pandanus season follows upon that of the breadfruit and during its seasonal peak it is the major food but its over-all importance is considerably less than that of the breadfruit.

Other Uses

The leaves of the pandanus were once perhaps fully as important in the native economy as the fruit. The plain mats used as bedding, floor covering, etc., as well as decorative mats and items almost forgotten by the present generation are woven principally from pandanus leaves. The long leaves are stripped or are gathered from the ground, trimmed, rolled so the recurved cross section will be flat and stored indoors. Later the spiny midrib is removed and the blade split into segments of desired width. Color contrasts are obtained by using leaves that have cured to various degrees, by dying, and by introducing other fibers that are colored or readily dyed.

Pandanus leaves also provide the thatching material for roofs and sides of the traditional house, although to an extent this has been superceded by introduction of corrugated iron roofing under the Japanese and, temporarily, by discarded American construction materials brought from Majuro. For use the pandanus leaves are assembled into panels made by folding the leaves over a long slender support, usually a split pandanus prop root, and stitching them in place. These units, often 5 or 6 feet in width, are overlapped as shingles and tied to the house framework. Such thatching makes a satisfactory roof for about three years or so but lasts much longer as walls. According to a legend this method of using pandanus was brought to the Marshalls long ago by wandering Gilbertese; before this, the Marshallese had used the flat leaves of the fern, *Asplenium nidus*.

The wild pandanus, Edrwan, is also valued for its tall straight trunks, sometimes used as supports in house construction.

Factors Affecting Production

No major pests were observed. A great many varieties of this fruit are found throughout the Pacific and it is possible that varieties superior in some respect to those now present on the atoll may be found. Production can easily be increased simply by planting more trees, however, so the objectives of any introduction should be longer bearing period and additional fruit characteristics.

Taro and Other Araceous Plants

The native taro of the Marshallese is *Cyrtosperma chamissonis*, Iaraj. The more widely known *Colocasia esculenta* was apparently introduced by the missionaries and its native name, Kötak, came from Kusaie, probably with the plant; it is also called Hawaiian taro. Both green-stemmed and purple-stemmed colocasias are present and there probably are other varieties not observed by the writer. Two other araceous plants are here considered with the taros although definitely not included under that name: Wöt in Kabilin̄ is a species of *Xanthosoma* recently introduced and is of little significance to the present agriculture. The native Wöt is *Alocasia* and, according to Anderson's check list, another species may be included with *A. macrorhiza* under this name.

Colocasia

The introduced Hawaiian taro is valued only for its starchy "root" which by some is considered superior to the native cyrtosperma. In keeping with the Marshallese disinterest in leafy foods the edible leaves and stems are not utilized at all. In general the culture and use of colocasia are similar to those of the native taro discussed below but a few plants, possibly an upland variety, were observed growing on the well-drained soils of the island interiors.

Cyrtosperma

No varietal differences are known. The entire plant increases in size with age, however, and the huge leaves, 8-10 ft. tall of old plants may not be

immediately identified with those of the more common smaller plants.

At one time, Iarej (Iaraj) ranked with, or perhaps exceeded breadfruit and pandanus. Today the evidence of its declining importance is clear for perhaps less than one-tenth of the pits prepared for its culture are growing significant amounts of taro. These pits were excavated to the ground water level in the sandy island interiors where the water is free of salt. The pits vary in size and shape but are commonly oval or oblong with flat bottoms 20-40 ft. long and 10-20 ft. wide. Presumably the builders made use of such natural depressions as existed but it is apparent that the pits were largely man-made. Although weathering has softened the outlines, the outer rims of the pits are commonly raised somewhat above the surrounding land, marking where the excavated material was dumped. Soil profiles on these rims are shallower and younger than those adjacent. On Ül-en' Is. taro is grown in the mucky margin of a large natural depression but cannot be extended over the somewhat brackish peat that occupies most of the basin.1/ Elsewhere the pits are concentrated in the interiors of the wider lands such as parts of Arno, L'angar and Ine Is. where constant fresh water was assured. Within these areas some pits are immediately adjacent so the spoil forms a high wall between; others are well separated. The separate pits and such random occurrence suggest no orderly construction. Certainly each pit was an undertaking of considerable magnitude, involving the excavation of one- to several hundred tons of sand with crude tools and baskets. Labon, a very old man of Arno Is., recalls that a pit was dug in the early 1900's but it seems probable that this was the last or among the last constructed on the atoll. No one else has any recollection of excavation and the condition of all observed suggests very considerable age. According to Lijömmar the pits on his land at Ine village were there at the time of his grandparents. A legend states that the pits on Arno Is. are the footprints of a man who walked across

1/Later analysis (Part I, Table II) shows the Ül-en' Island peat to be free of salt.

the land.

Elsewhere in the Pacific newly excavated taro pits are prepared for use by placing quantities of organic matter in the bottom. Presumably this was also true on Arno and organic debris is still added to the pits in use. In consequence the bottom soils are calcareous mucks with the water level lying close to the surface. After heavy rains the water may stand to the depth of several inches in the pit for at least a few days. Other than planting and harvesting the principle culture of taro is weeding. Such plants as the vigorous Wedelia extend outward from the pit margins and woody species spring there also. There are relatively few plants, such as Cyperus, the fine-like Clerodendrum and Hibiscus tiliaceus, that grow directly in the wet muck. The principle reason given for not growing taro now is that its culture involves too much work, although the prepared food is preferred to rice by some.

Use as Food

During the breadfruit season taro is rarely eaten but is saved for the months after the pandanus peak. The larger corms are harvested as needed and boiled or baked. Other preparations (Jukjuk) are made by baking mixtures of the cooked root with sugar and coconut cream or banana. At the present level of cultivation the Cyrtosperma and colocasia together rate as a rather minor component of the diet, although important to a few families and as a general reserve.

Factors Affecting Growth

No major pests were noted. The typhoons of 1905 and 1918 were said to have killed taro by flooding the pits with salt water but such storms are rare. Young taro (Cyrtosperma) in pits on Arno Is. is reported to have been killed by immersion, probably complete, in fresh water following heavy rains.

Without observation elsewhere on the Marshalls it is somewhat hazardous to speculate on the reasons for the decline of taro from its former position as a major food crop. Dr. Mason has pointed out that with a decrease in the absolute powers of the Iroij, brought about by missionary and German influences, went a gradual lessening of the landholders' responsibility to his rulers. This may well have led to the neglect of the more difficult or less rewarding tasks. It was during the same period, however, that extension of the coconut groves took place; under the stimulus of the copra trade land clearing, care of coconuts and copra manufacture required much more labor than previously. Yet another factor was involved, perhaps the decisive one: the pigs introduced by the missionaries thrived and multiplied until on Arno Is., according to Labon, taro and arrowroot were almost eliminated and new coconut plantings were damaged. Probably urged by the Germans the residents in "about 1900" declared an open season on all pigs at large, an action that reduced the depredations. Nevertheless, the taro crop had been wiped out for a period. A similar story is told by Lijömmar; pigs ruined the taro near Ine and the pits were abandoned and remain largely so to this day. The destruction of taro by pigs at a time when the native agriculture was already changing may well account for the conditions noted, apart from other factors.

Elsewhere in the Marshalls taro continues to be an important food and its culture might well be encouraged on Arno, particularly since it is already well accepted and the pits are present.

<u>Alocasia</u>

Although sometimes found with the Iarej this plant is more common on protected and fertile well-drained soils. Cultivation is largely negative, consisting of not destroying it when other plants are cut. The Wȯt is an emergency food, used when others are not available, as following the pandanus

season. The corm is peeled and baked a few hours but even then may be too irritating to eat because of the minute calcium oxalate crystals. Juice of the green husks of the drinking nuts is believed to lessen the irritating principle but even after treatment the root may still be inedible. There is a belief that some people know what part of the root is responsible for the irritation and hence have more success in its preparation, but there is no botanical reason to suppose this is true. Since Wȫt provides an acceptable food when free of the irritating principle, some attention might be given to taxonomic and varietal differences and to methods of preparation for elsewhere in the world some highly irritating plants of this group are rendered edible by sufficient treatment. Substitution of introduced Xanthosoma may be much simpler.

The large leaves of Wȫt and probably of Iarej as well are used for wrapping fish and other foods for baking. The flowers of Wȫt have been used for perfuming oil.

Polynesian Arrowroot, "Makmök"

Tacca leontepetaloides, the "arrowroot" of the region, exists as a semi-domesticated plant, flourishing with little care wherever the soil is salt free and only moderately shaded. It is spared when other vegetation is slashed in the groves and benefits from this weeding. In densely shaded areas, such as the interior of Arno and the wartime abandoned groves on L'angar, tacca is soon eliminated as a crop; this was well recognized by the people of L'angar in explaining the small amount of tacca now found there.

Propagation scarcely offers any problems. The small rootstocks are left when the larger ones are harvested; moreover, the plant fruits abundantly. The potato-like rootstocks are sometimes stored for a short time in the pits along the beach but soon sprout. Although it is possible to eat them baked,

usually the starch is extracted. For this the clean roots are grated raw and placed in a coarse cloth bag. Water is poured through as the mixture is stirred, thus washing out the starch and leaving the fiber in the bag. The starch is collected and dried, yielding a white high quality product that can be stored.

Although not present in quantity on all islands the makmök is sufficiently abundant on the atoll to constitute an important emergency food source in addition to its normal use. Observations suggest that the latter use is limited more by the labor involved in harvesting and preparation rather than by available supply. Inasmuch as this plant is adapted, productive, and can be successfully grown beneath the coconuts, at least in the better soils, some attention might be given to devising simple equipment that would facilitate starch extraction.

Bananas

On L'angar there is a legend of how once during a period of starvation a man in chase of a rat carrying away a pandanus nut discovered a grove of bananas. This is reputedly the origin of a variety, Jorukwor, regarded as indigenous, and the exact spot is marked by the sleeping man -- a massive piece of protruding beachrock. There are other versions of the story but discovery of this banana is common to all. The deep moist soil of this spot is regarded as the best for bananas, and probably is, but very few grow there now. Nowhere on the atoll does the banana grow wild and it is probable that even the Jorukwor was an ancient introduction. Most of the present bananas are known to have been introduced and often the circumstances attached to the introduction are remembered, as on Arno Is. where two weeds were reputedly brought in with the soil attached to bananas introduced by German Catholic missionaries early in the century.

Culture

The varieties of bananas now present on the atoll were not catalouged but they seem to be few. One or two cooking bananas are grown as well as one or more edible sorts; presumably all of these can be classed as varieties or sub-species of Musa paradisiaca. The Chinese banana, M. nana, is recognized as desirable because the dwarf plants are much less subject to wind injury and it would be more widely planted if seedstocks were more abundant.

The banana is propagated by means of the large offshoots. Since the number of these is usually not great under Arno conditions and one or two are often left as replacements, multiplications of seedstocks is slow. Its growth, of course, is limited to the salt free, somewhat more fertile areas protected from the wind. Bananas seem to be planted in three general areas: (1) In the house courtyards, (2) in the groves adjacent to the house, and (3) on the sides and bottoms of the taro pits.

The graveled courtyards are kept free of organic matter and leaves of the bananas are generally chlorotic because of a deficiency of available iron. Young plants, particularly, are occasionally almost completely yellow but usually survive and become greener, generally accumulating iron during wet periods when the saturated soils favors its availability. Severe deficiency increases the time required for fruiting and, of course, reduces yield. For optimum growth and yield the banana also requires moderately high levels of soil nitrogen, ordinarily not found in the courtyard locations. Occasional plants are vigorous with large dark green leaves but these exceptions suggest only that the family sanitation does not comply with the Marshallese standards.

Planting sites in the second group are only arbitrarily separated from those in the first but in general have greater shading and somewhat better soils. Acute iron deficiency is rare, although sub-acute symptoms are often

seen. Commonly pits are dug and filled with organic refuse before the shoots are planted; similarly, sand pits dug for the maintenance of walks are often filled with household rubbish, then closed and a banana planted above. Several of our soil profile pits were left open upon request for the same purpose. Such preparation is considered good practice by the more alert growers and obviously is an excellent, albeit laborious, means of providing the fertility needed by this crop. The method is used in probably no more than 25% of the plantings made. In some soils no marked benefits would be expected and in one instance detrimental effects from this method were reported.

On planting sites of the third class, bananas usually grow well with occasional weeding as the only culture. On the lower slopes and mucky bottoms of the taro pits nutrients are in fair supply and moisture abundant but most of these areas are too heavily shaded for a maximum growth.

Use

Writing of conditions on nearby Majuro atoll, Spoehr suggested that perhaps bananas figured more as food gifts for visiting Americans than in the local diet. On Arno the banana seems to be a well-liked fruit and is sufficiently well-regarded that many people, though not all, are willing to give it the necessary minimum culture. Though children and honored visitors occasionally monopolize the available supply, this seems to be due more to generosity and a desire to please rather than to indifference towards the fruit. The present plant numbers and yields do not seem great enough for the fruit to be of much nutritional significance for the average person but it does provide some variety in the diet.

Factors Affecting Production

No major insects or diseases were evident. The fruit is usually gathered green to avoid theft and damage by rats.

The effects of iron and nitrogen deficiencies have been mentioned but there is no doubt that these could be avoided or overcome. Applications of soluble iron to very yellow leaves in Ine village produced a rapid greening but such treatments are neither feasible nor necessary. Maintenance of a deep surface mulch of organic matter would eliminate deficiency of iron, as well as supplying the nitrogen and other nutrient elements required in quantity for rapid growth. Such a mulch, if composed largely of low-nitrogen material like coconut husks, might lead to temporary nitrogen deficiency through microbial tie-up of this element but the condition would be only temporary. If herbaceou or leguminous material were included in the mulch even such temporary tie-ups would be unlikely.

Production of bananas could be increased many fold simply by further plantings on the soils known to be most favorable, such as the phosphate areas, taro pits, etc., and on other soils using mulch fertilization. The principal limitation to such mulching is the labor involved in carrying the material; by scattering the plantings throughout suitable areas, rather than concentrating them, the distance to available materials can be kept very low. Around the house areas, where surface organic matter often shelters centipedes and scorpions, pits filled with organic matter would continue to be the best insurance of satisfactory growth.

Papaya and Lime

It is probable that the papaya was introduced on the atoll very early in the century but it is nowhere abundant. It is usually found as a somewhat neglected tree near the dwelling places and persists as much by reason of its heavy seeding as by deliberate planting. The tree often suffers from a sub-acute iron deficiency. The only variety observed has a mediocre fruit and the plant is usually allowed to grow too tall. Unless picked green the fruit is

damaged by rats. There are occasional exceptions but generally the fruit is of very minor importance.

Present interest in the fruit does not warrant much attention to it. Introduction of better varieties and provision of knowledge about their culture and vegetative propagation are the obvious needs and might bring about further acceptance of the fruit.

Large lime trees are relatively scarce but numerous younger plants were observed. The common planting site is in the shaded interiors or on taro pit slopes. Trees planted near the houses often suffer from a severe chlorosis caused by iron deficiency. The quantity of fruit produced is much too small for any significant effects on the vitamin C intake of the average individual but the lime ranks with the kino fern as the major flavoring agents used on the atoll.

Mulching or incorporation of organic matter beneath the young trees as suggested for the banana are the obvious cultural recommendations. The single variety is of good quality and apparently propagated by seed. Introduction of additional varieties is much less important than introduction of other citrus adapted to the atoll habitat.

Other Introduced Food Plants

The Chile pepper (Capsicum frutescens) is commonly grown near houses for its fruits which are used, though sparsely, in cooking. In a few areas (e.g. the phosphatic soil on Tak-lïb Is.) an introduced pumpkin grows as a semi-wild plant; its occasional fruits are eaten. Two varieties of sweet potatoes, "Bitato", were observed but this crop is grown only rarely and is of no significance in the general diet. A small clump of sugar cane, To'o, was found growing in an old taro pit near Ine but apparently no effort is being made to increase this despite a general liking for sweets. The presence of the yautia,

Xanthosoma, was noted under the discussion of taro. A small-fruited fig, Tōbro (Ficus tinctoria) introduced from Jaluit, is found occasionally on the atoll and does not appear to have spread beyond the original planting some years ago. The firm marble-sized fruits are boiled, mashed and mixed with grated coconut; thus it provides occasional variety for few individuals. A single tree of Kūrak (Inocarpus fagiferus) grows and fruits in the garden of King Tobo in Ine village and a single mango tree was planted on Arno Island after the war.

Other Introduced Plants

Neglecting horticultural varieties, roughly 40% of the species now recorded on the atoll have been introduced in historic times. In addition to the introduced food plants mentioned previously and a few weeds of foreign origin, several of the other exotics have some importance for the people of Arno. With their fondness for flowers they have welcomed ornamentals and here, as throughout the Pacific tropics, hibiscus and frangipangi (Plumeria) are conspicuous. Oleander, Croton, and Bougainvillea are present but rare, the latter represented by a single plant on Arno Is. Acalypha and species of Polyscias are hedge plants in Ine village, presumably by reason of Japanese introduction. Much more widely distributed are two species of Pseuderanthemum; they are used as hedge plants and the fleshy leaves of P. atropurpureum, Tirosbin (= pink tearose), are gathered as pig feed. The herb Ocimum sanctum is used for scenting coconut oil. The small pink fairy lily, Zephyranthes, blooms periodically in the graveled yards where it seems to thrive. The much larger Hymenocallis littoralis, Kiop wau (= Lily of Oahu) was presumably brought by Hawaiian missionaries but is now naturalized in the open groves. Several other garden flowers are found in smaller numbers, presumably the hardy remnants of successive waves of introductions. Similarly, a few plants of cotton, Gossypium barbadense persist though uncultivated. Another plant called "Kotin"

is the kapok tree, <u>Ceiba pentandra</u>; its floss is occasionally used for pillows. According to Felix, seedlings were sent to him in 1915 by a German living on Ponape. Planted on the fertile phosphatic soil of Tak-lïb Isl. they have flourished and spread but the tree is not found elsewhere on the atoll.

Seeds of tomató and watermelon as well as those of a number of garden flowers were brought to the atoll as a gift to the people from Mr. Anderson. Observations on these plantings, as well as on a small garden established by the writer, indicate a very high percentage of failure. The use of artificial fertilizers, composts or mulches will be necessary for successful growth of most common garden crops. In this connection, the shallow fresh water peats of old taro pits may be used to surface small garden spots for a few preferred plants such as the tomato.

<u>Indigenous Plants of Value</u>

Virtually all the indigenous plants figured in the native materia medica and many had other uses. The loo, <u>Hibiscus tiliaceus</u>, is a fiber plant of value. In habit it resembles a gigantic bush and is found singly or in very small groups in moist soil and abandoned taro pits. Although here considered indigenous, its limited occurrence and lack of aggressiveness suggest that very possibly it, too, is an ancient introduction. The tall straight poles arising from the old horizontal branches are stripped for their tough inner bark. This is used as cordage or as an easily dyed fiber for mat weaving, etc.. The inner bark of arme, <u>Pipturus argenteus</u>, was relied upon for fish lines and is still used when imported lines are not available. The bark of <u>Triumfetta</u> provides a colored fiber for weaving.

The grasses, <u>Thuarea</u>, <u>Elusine</u> and <u>Paspalum</u>, and especially the ubiquitous legume, <u>Vigna marina</u>, provide much of the feed consumed by chickens. The leaves of <u>Ipomoea tuba</u> are gathered for pigs. In addition to the uses of its tough

wood, the fruits of the mangrove, Joñ, Bruguiera conjugata, is a source of the black dye used for decorating mat fibers. Likewise, roots of Morinda provide a yellow dye. The fronds of a fern, Kino, Polypodium scolopendria, are widely used for the flavor imparted to fowl, etc., baked in its leaves. The nuts from the two species of Terminalia are used occasionally but the supply is very limited. Barringtonia fruits are used as fish poison but only by children. The wood of Guttarda was used for fire plows, not much in demand at present. Prior to cooking, octopus is covered with leaves of Messerschmidia and pounded. Tests of the dried leaves (by J. B. Sumner, Cornell University), however, show no appreciable amounts of protein-decomposing enzymes.

LIVESTOCK

Other than dogs and cats and occasional pet pigeons and reef herons, the only domesticated animals now on the atoll are pigs and chickens, first introduced by the Germans and missionaries. Turkeys and ducks are said to have been present prior to the war.

Poultry

Old men still remember that before the missionaries came the jungle fowl lived in quasi-domestication on these islands; they were valued for the cockpit. Itself an ancient immigrant, brought in some forgotten canoe, the jungle fowl was absorbed by the introduced chickens although some of the plumage characteristics are still seen. The present population has resulted from a mixture of breeds, mostly now unrecognizable except for the feather pattern of the Frizzles, said to have been introduced by the Japanese. The Arnoese do not eat eggs and the chickens are kept only for meat. Body size is usually quite small and the merits of the stock are largely hardiness and the ability to forage. The chickens are kept penned only rarely and their food consist of grasses, seeds (particularly of Vigna), insects, etc., discarded coconuts and the meager

household scraps. Young chicks are sometimes fed grated coconut or coconut and chopped grass. The hens "steal" their nests; they are good mothers and commonly bring off broods of from 12 to 15 chicks. Subsequent mortality is high and three-week-old broods seldom number more than 6 to 9. Food, weather and disease doubtlessly account for many of these losses but predation by cats is probably much greater than the people concede.

Despite these hazards the chickens are abundant and of some importance as a protein source, although the use seems to be limited to special occasions. They could be more important for there is additional poultry range outside of the well populated areas. Improvement of the existing stock and practices is quite possible but only within certain limits: (1) There is no reason to emphasize egg production until the time when people accept eggs in their diet. (2) Feed supplies will continue to be much as described above, with an ample native range and only limited supplemental feeding. Additional coconut could be fed as in the Philippines, but other supplements are not in sight. Hence, feed will probably continue to limit growth. (3) Early mortality could be decidedly decreased by confinement and supplemental feeding of the chicks. Other changes in present practice cannot be expected, except possibly within the villages, for the chickens must range widely to feed. The hardiness, disease resistance and foraging ability of the present stock are necessary attributes. Thus, the only practical recommendation is introduction of males of some vigorous, fertile, medium-weight breed such as the meat-type New Hampshire to upgrade the native stock.

The Civil Administration native school at Majuro has recently imported ducks. Various breeds, including the Muscovy, should be tried for ducks are worthy of thorough trial in view of their previous presence and the possible food supply of the shallow beaches.

Swine

The rapid increase in numbers following introduction and the consequent disastrous effects on agriculture early in the century have been mentioned in connection with taro culture. In the more populated areas pigs at large are still prohibited, although enforcement is not always strict, and there an occasional family pig is kept in a stone walled pen. In a few areas pigs range at will with consequent destruction of all edible plants.

A very rough estimate of the total number of pigs in the atoll would be between 100 and 150. Their numbers were greatly reduced during the war and some of the Guam breed were brought in during post-war rehabilitation efforts. Crosses of this adapted breed with the runty local animals have resulted in some upgrading but the effects do not seem very marked. In two instances second and third generation animals, still with 25 or 50% Guam blood, approached the local breed in size.

This directs attention to the nutritional status of the animal. Confined animals almost certainly receive a very low energy ration, unless deliberately fattened, for leaves, household scraps, etc., can seldom be fed as sufficient quantities. Coconut is virtually the only concentrate and it is not usually fed in quantity except to pigs fattened for lard production. Pigs at large appear to fare somewhat better but unless their numbers are small in relation to area ranged they soon wipe out the plants that supply their feed. It is obvious that protein intake must be minimal. Of the minerals, calcium should be adequate because of the leafy feeds and incidental ingestion of soil. The sources of phosphorus are limited although they may suffice for the low energy ration.

Thus it appears that both animal numbers and attempts to improve the breed will be restricted by the nature and amount of food available. Increasing

the area of "open range" would provide more food but would eliminate the possibility of growing tacca, bananas, taro, etc., there. Pork is a highly desirable food, providing animal protein and adding much needed variety to the diet, and the lard is valued as well. A moderate increase in the swine population is feasible but under present conditions any considerable increase would be at the expense of other foodstuffs.

WOOD SUPPLIES AND REQUIREMENTS

As pointed out, much of the extension of the coconut groves was at the expense of the original forested area. Thus the Pisonias which Agassis commented on when he visited the atoll in 1900 are nowhere abundant now. Today there is little to show the nature of that forest at its best; the "jungle" areas in the interior of Arno and L'angar Is. are clearly secondary forest. The only wooded area that may have some affinities with the original forest is on the atypical soils of Tak-lïb Is. Here are a few large Pisonia, Cordia, Intsia (Afzelia) together with other species, but the introduced Ceiba suggests a very considerable disturbance.

Forest Situations

Apart from the above it is convenient to recognize four "forest situations," although these are not valid ecological units. (1) On exposed shores and recent lands the shoreline brush is composed largely of the sprawling Scaevola with a variable amount of Messerschmidia. On sandy lagoon shores and interior saline flats Pemphis, or rarely Suriana, is more likely to dominate. This type is of value as a windbreak and some of the woody stems are used.

(2) Merging with the above is the mixed brush, consisting of Scaevola and Messerschmidia together with tree species, such as Pandanus, Guettarda, Ochrosia, Ochrocarpus, Terminalia, Morinda, Intsia and occasionally, Barringtonia and Calophyllum. The trees are young and the species present depend on the

degree of salinity and seed supply. Such mixtures often represent stages in the vegetational succession following disturbance by storms or clearing. Thus, without periodic cutting the trees would eventually dominate. Occasionally one finds small stands of older Ochrosia, Soulamea, Guettarda, or various mixtures where this has occurred. Elsewhere the mixed brush areas are transition zones; a mixture with Pandanus predominating is often found on the beach rampart, tapering in height from the outer shore brush to groves inland. The mixed brush types are widely distributed and provide a variety of different woods and shapes for local use.

(3) Secondary forests on the dark salt-free soils of the interior consist of Allophyllus, Premna, Morinda, Pipturis and Guettarda, together with the wild Pandanus and sometimes Intsia or young Artocarpus. Ixora is locally abundant on Arno Island, and Hibiscus tiliaceus may occur in moist spots. All of the areas of such forests are relatively young and usually they have originated as an understory in abandoned coconut or breadfruit groves. A high proportion of stems tend to be rather crooked but the stands are sufficiently dense to largely overcome this. The relatively long, small diameter poles are well suited for framing thatched houses and are readily cut and handled. Hence this forest is of value but its occurrence is limited to a few islands and there largely owes its existence to neglect. Several of these species are good timber trees elsewhere in the Pacific but on Arno the crooked stems of young trees and the sprawling form of older relics suggests this is not true on the atoll habitats. Breadfruit (Artocarpus) is the noteworthy exception.

(4) Several small areas of mangrove swamp occur, chiefly in inland depressions. Bruguiera is the principal species, forming dense pure stands on the shallow brackish peats and rocky depressions of L'angar, Tinak and other islands. Elsewhere it occurs with Lumnitzera in small brackish basins. The

young poles are straight but the older trees tend to be crooked and seldom exceed ten inches in diameter. On Bikareij and Namwi Is. Bruguiera forms small pure stands along the margins of saline flats and inlets as well as mixing with Sonneratia. The inland mangrove areas are nearly valueless for agriculture but are of decided importance to nearby residents as a source of tough poles and durable wood.

Other sources of small diameter poles are the woody invaders of coconut and breadfruit groves but their abundance is in proportion to the intensity of clearing. Large trees of Pandanus, Calophyllum, Ochrosia, Terminalia and Intsia are occasionally found as isolated individuals along protected shores or in door yards. These are usually too large to be utilized with available tools. From time to time the large breadfruit die and decay without utilization for the same reason. Root suckers of breadfruit may form colonies that occasionally, as on the Arno Is., take on the aspects of a forest stand and are excellent sources of straight workable trunks.

Species and Uses

A list of woody species used by the Marshallese would simply be a catalog of those occurring for almost all are utilized. The durability of Bruguiera, Lumnitzera and Intsia in contact with the soil, as well as the toughness of these, Ochrocarpus and Calophyllum are known. The wide use of breadfruit for canoes has been mentioned and it is worked in many other ways. Although less abundant than now formerly, Cordia, workable and tough, serves for the end-pieces of small canoes, and is made into paddles, platform boards, pounding bowls, hatblocks and for similar incidental carving. In addition to the breadfruit Soulamea provides support beams for canoe outriggers and curved pieces of it, as well as the stems of Scaevola, are used for the arched braces to the outrigger float. The very hard Pemphis is spliced on as mast tips and

onto sail poles as a bearing frog against the mast; it is also used as the protective keel. Pemphis, Randia and Ixora are made into cage-type fishtraps and Premna, Allophyllus and Lumnitzera are the preferred woods for fishing poles. Net floats have been made of the very light wood of <u>Hibiscus tiliaceus</u>. Straight poles or posts of almost any species are of value for house building but differences are recognized, thus Barringtonia is considered a very poor wood. Coconut is occasionally used for heavy posts but is not durable in contact with the soil.

<u>Construction Requirements</u>

The discontinuance of the wartime base on Majuro provided a bonanza of construction materials that still has its effect on the architecture and construction of Arno. The abundance of frame and frame-thatched hybrid dwellings tends to obscure the fact that housing of sawn lumber is simply not compatible with the present average income of the Arnoese. Barring other bonanzas, most of the people will go back to living in thatched houses as decay and obsolescence claim the present shanties. The few pre-war frame buildings were largely Japanese houses or stores and copra sheds. It is easy to calculate that at present-day prices there will be very little construction, even of Marshallese-size houses, with purchased lumber. Hence the need for pandanus thatch and small diameter poles for framing is likely to increase in the future. Since rainfall stored in cisterns provides the main fresh water source for the village areas, the demand for metal roofing is a reasonable one and will continue strong. Boat construction will continue to require wood, either solid breadfruit logs for outrigger canoes or sawn lumber for the more conventional small boats.

Because of the considerable difficulties of transporting wood some individuals or groups may lack but, at present, there are ample supplies of wood and thatch for building on the atoll. Continued clearing and

better maintenance of the groves will automatically reduce wood supply. Future prospects are for diminishing supplies and somewhat higher demands.

Future Measures

Suggested measures for improving wood supply depend to some degree on education or supervision and hence are not practicable under existing circumstances. They are: (1) Education in and encouragement of simple care of woodland areas not in conflict with agricultural use. Thus the productivity of the mangrove swamps, in terms of useful material, could be increased by simply cutting or girdling oversized and crooked trees. Breadfruit is potentially the most valuable timber tree and its planting should be encouraged beyond the need for the fruit.

(2) It is doubtful that any introduced species would be superior to breadfruit in rate of growth or general utility but Casuarina and the bamboos have special merits. The Casuarina is a strand tree, occurring on coral shores elsewhere in the Pacific and might succeed in the beach zone. The form of the tree is fair to good and the wood hard but subject to splitting. The bamboos are so generally useful elsewhere that they are worthy of extensive trials. Mr. Kessel of the Civil Government School at Majuro reported that a planting of bamboo made there has failed. There are several genera and species of bamboos, however, and these should be tried on a variety of planting sites, especially the old taro pits and, moist soils of the interiors, and on the three areas of phosphatic soils.

(3) The possibility of a small portable sawmill serving one or more atolls should not be overlooked, although admittedly a project of the future. Presumably this would entail cooperative ownership, and operation would require mechanical skills but these problems have already been met with some success in the acquisition of atoll-owned ships. The capital investment required would

amount to, say, one-fourth to one-half of the sum represented by the atoll's copra production for a single month and hence is by no means prohibitive. The real problems involved are satisfactory transport of the mill from place to place and of the logs to the mill, as well as rigorous control of cutting. The source of logs would be very largely breadfruit and coconut, the latter yielding "porcupine wood," suitable for use if kept dry. Obviously such cutting could not be permitted to reduce production of food or copra and it need not. A replacement program for overage palms and removal of over-mature or crowded breadfruit would provide a continuous supply of sawn lumber from material now largely wasted.

FOOD SUPPLIES AND NUTRITION

The appraisal of food supply and nutritional significance can be in only the most general terms for the writer has no estimates of productivity and consumption, nor are there nutritional data for many components of the diet. Further, our observations were for a limited period in the season of abundant food. Nevertheless, there are ample signs that at present this atoll is well supplied with food, so far as total quantity is concerned. The sustained production of copra is an obvious guarantee against near-starvation levels. The unused supplies of arrowroot, breadfruit and alocasia, the decrease in fishing and taro culture, and the rather minor attention to food storage suggest that such food shortages as occur are far from critical. There may well be times when the diet is limited to the less desirable foods or those obtained more laboriously -- to "fish, crabs and copra" as was said on L'angar -- but the actual calorie intake can be maintained. Further than this, some food is imported, although primarily for the high income families.

Nutrition is one of the fads of our time as well as a subject for sober investigation, and some of the recent reports on the Pacific areas contain

facile judgments on the adequacy of native diets. Without clinical evidence of deficiency or detailed appraisal of diet, supplemented with analyses, such judgments can scarcely be more than opinion. To begin with, from all accounts the Marshallese thrived fairly well on their original island diet which contained no leafy vegetables, only pandanus and possibly bananas as fruit, and certainly no milk. Rather than the original diet it is the subsequent modification of it that provides cause for concern.

From considerations in other paragraphs it is evident that the agricultural production of the atoll in terms of calories far exceeds present dietary needs, although large percentage of this is in the form of copra. Thus it may readily be calculated that about one-third (ca. 15 to 16 tons per month) of the present copra production would alone fully supply the energy requirements (2500 calories per person per day) of the entire population (1200). Although the idea of such a diet is fantastic the figure demonstrates the importance of the coconut as a reserve and points out that the amount actually consumed is only a fraction of that prepared for export. In fact the contribution of coconut to the average calorie intake is probably greater than commonly realized, for although the mature nut is scarcely eaten when other foods are available the consumption of the soft flesh of drinking nuts and of iu (cavity tissue) is very appreciable. Much of this is eaten outside of the regular meals and often away from the dwellings. It seems likely that coconut ranks near breadfruit and pandanus as major calorie sources, with the protein foods, tacca, taro, etc., and imported foodstuffs ranking well below.

There is reason to believe that fishing is carried on to a lesser extent than formerly but the principal protein sources are still fish and seafood. Pork and poultry can make but a small contribution to the average requirement. Breadfruit and taro are considered low protein foods but, according to available

analyses, if eaten in sufficient quantity to satisfy the daily calorie requirement they supply from one-fourth to one-half the established protein requirements of the normal adult, although the quality of this protein is unknown. Analyses of dried pandanus flour and preserved breadfruit from Kapingamarangi (kindly supplied by C. D. Miller, H. Denning and A. Bauer of the University of Hawaii) show the dried pandanus, and hence presumably the original fruit, to be a poor protein source. Flesh of the immature coconut may have a much higher protein-calorie ratio than the mature nutmeat.

Although concern has been expressed over the starchy diet of breadfruit and taro the Hawaiian workers have demonstrated that these foods are, in fact, much superior to white flour and rice in respect to the B vitamins and calcium. The high calcium content in araceous plants may be of no value, however, because of the presence of oxalates. Breadfruit is considered a fair source of vitamin C, even when cooked, and this may be of considerable significance in view of the quantity consumed. Assays of the two Kapingamarangi foods bear out these results and suggest that the pandanus is a fair source of vitamin A. Although fluid from the drinking nut contains relatively small amounts of accessory substances, the quantity consumed must be considered in evaluating its contribution. Fish, crabs and other seafood provide minerals and several of the vitamins, as well as proteins, in proportion to the quantity consumed. Vitamin D is presumably of little concern except for infants and some women continuously sheltered from the sun.

These considerations suggest that the adequacy of the native diet may have been maligned unduly, although estimates of the calcium, phosphorus and vitamin C status are weak. But two unhealthy trends in the dietary habits are appearing: The substitution in part of white flour, sugar and rice for the local carbohydrate sources, and the reputed reduction in fishing. Both of these

tendencies are most marked in the Ine village area because of the higher income and greater foreign contacts, and are of lesser importance in the more remote portions of the atoll. Extension of these tendencies will inevitably lead to deterioration in quality of the diet for the lack of leafy foods, fruits, and additional protein sources leaves but little margin for safety. Yet increase in purchasing power encourages such extension and it probably cannot be avoided, barring actual controls. Suggested positive measures are mandatory enrichment of flour, at such time when its potential use is sufficient to warrant this, improved fishing methods (see report of the Marine Biologist) and diversification of the present subsistence agriculture, adding new foods while encouraging use of the old to provide both variety and nutritional quality in the modified diet.

It must be pointed out that the foregoing estimate is largely based on impressions and a few analyses. Data on the actual consumption of food, both local and imported, as well as nutritional assays and related evidence, are necessary for accurate evaluation and prediction.

SUMMARY OF THE AGRICULTURAL SITUATION

The agriculture of the atoll is thus seen to have two aspects, subsistence and export. The present subsistence agriculture is derivative and still rests largely upon the original food plants, cultural methods and uses of native vegetation. Introduced plants have had only minor effects on the subsistence agriculture and diet. Originally, agriculture and fishing were complementary subsistence activities and to a large extent still are. The relatively small contribution of introduced animals to the diet arises from their limited number rather than local acceptance. Some of the changes occurring in the past half century or so are displacement of taro as a major food, a great increase in the cultivated area and consequent elimination of the original vegetation, greater dependence on imported goods, and the beginnings of substitution of imported for

local foods. The pattern of land holding (see report of the Anthropologist) does not always favor fullest use of the land, particularly for subsistence crops. None the less, the subsistence agriculture is largely adequate and capable of expanding to support a considerable increase in population.

The export agriculture is concerned wholly with copra, which is the product of an indigenous tree cultivated with practices that are only modifications of those employed in the native agriculture. By those concerned with the economics of such areas, increases in export agricultural values are often looked upon as the most promising means of providing the goods and services necessary for material improvement of the people. We have already estimated very grossly that for Arno about a two-fold increase in copra production is about the most that can be hoped for under existing practices. Such an increase is a worthwhile objective but a limited one, even when combined with moderate increases in quality and production efficiency. Further, prices for copra in the world markets have been subject to wide fluctuations in the past and may be in the future.

Such considerations lead to the question of producing other export crops in order to increase the total income of the area and minimize the risks inherent in a single-crop agriculture. Unfortunately the present prospect of any considerable gains by such means is exceedingly dim. In the entire Marshalls the total area of protected land suitable for such crops is small and it is scattered piecemeal, precluding any large single developments or mechanization, and complicating production and shipment. Taking Arno as representative, even in favorable rainfall regions the inherent productivity of the soils for most such crops is very low. The calcareous soils preclude some crops and without measures for maintaining or increasing fertility the success of others would be foredoomed. Finally, were a crop decided upon, discovering varieties and

cultural methods adapted to the area, the almost certain likelihood of pest control and fertility problems, and the considerable task of adapting the people's folk ways to the new crop would together require sustained skilled effort and supervision.

These and additional causes for pessimism are set forth by J. C. Ripperton in his 1946 report on Some Agricultural Aspects of Micronesia, vol. 17 of the USCC. Economics Survey of Micronesia. They are also implicit in the perceptive statement of Project No. E. 6, "Economic Development of Coral Islands" prepared for the South Pacific Commission Research Council. The one possible exception, suggested by Ripperton, is the production of fruits, truck crops, etc. on areas near American bases to supply garrison forces. Although localized in importance such markets are lucrative and this possibility should be developed fully. The price incentives, if combined with production guidance, would accelerate agricultural change in the areas influenced.

In the subsistence agriculture it is clear that many gains can readily be made and that, in addition, there are many possibilities that offer enough prospect of success to warrant some investigation. Improvement of the existing crops and crop types, cultural methods and utilization, are realizable objectives. Introduction of additional useful plants, of which there are many in the tropics, is an obvious and attractive prospect. The same considerations mentioned for new export crops apply to such introductions, however, and numerous failures are to be expected. Yet the choice is great, the investment involved is small, and a number have already been tested in part by former introductions of low islands. But even though successful, mere introduction is without value unless the plant with its culture is accepted by the people and fills an existing or created need. Moreover, plant introduction should be looked upon largely as a means of supplementing, not making over, the present adapted agriculture.

The limitations of agriculture have been mentioned. Some general and specific changes in the export and subsistence aspects have been suggested. Yet what is clearly needed for substantial improvement in this region is a long time program of on-the-ground investigation linked with education and demonstration. Both activities can be on a small scale if properly supported and staffed. At this stage, by making use of relevant information accumulated elsewhere in the tropics, well conceived emperical investigations could pay off handsomely for a time. The results will be of little value, though, without demonstration and education to bring about acceptance. Such extension activities necessarily reach beyond the questions of production to influence utilization and consumption. Thus, they might well be fitted into a larger program of education and assistance, embracing other aspects of native industry and welfare, but this is a question of administrative policy.

The people of Arno are extremely receptive to new ideas, even though subsequent retention and execution are rather less than outstanding. American technical capacity is highly regarded because of the war-time contacts, the Bikini tests and the medical successes against yaws, venereal diseases, etc. People would readily accept an extension program modeled after the familiar agricultural extension and home demonstration activities of the U. S., but adapted to their needs and level. Yet all extension work is presumptuous to some degree, implying the greater wisdom of the newer knowledge, and if such a program is not to disturb the values and the sense of security in the existing order it must be guided by anthropological as well as technical considerations.

Summarizing, for Arno Atoll we find that productive capacity in terms of value of agricultural exports is below maximum at present but this maximum is definitely limited. In terms of subsistence agriculture, the land, supplemented by the sea, is capable of sustaining a considerably higher population than is now present, provided the meager resources are used fully and intelligently.

ATOLL RESEARCH BULLETIN

7. The Plants of Arno Atoll, Marshall Islands

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THE PLANTS OF ARNO ATOLL, MARSHALL ISLANDS

by Donald Anderson

SCIENTIFIC INVESTIGATIONS IN MICRONESIA - PACIFIC SCIENCE BOARD

30 June 1950

This is a preliminary report on field work in botany during the period May 5 - 30, 1950, on Arno Atoll in the Marshall Islands.

1. To make possible the definite determination of species of plants referred to in Marshallese plant names.

2. To make as complete a collection as possible of Arno atoll plants.

3. To collect the Arno version of the Marshallese name of each plant species and variety collected.

4. To make tentative determinations of each species collected.

5. To correlate the Marshallese and the botanical names with each numbered herbarium specimen in order to make possible a careful study and check of the field identifications.

6. To furnish the other members of the study team with as much of this information as possible prior to their departure from Honolulu en route to Arno Atoll for their field work.

The major portion of the collecting was done on the island of Ine because of the easy access from Ine Village where the laboratory and quarters were established. Ine Island, which is situated on the south side of the lagoon, is thirteen miles in length and fairly characteristic of Arno Atoll floristically. Several species of Arno Atoll plants are missing from Ine Island, however.

The total collection on Arno Atoll was 169 herbarium numbers. Of these 134 numbers were collected on Ine Island. On a three day canoe trip to the north and west sides of the lagoon 35 more numbers were collected. Collecting during this trip was limited to species not collected in fruit or flower on Ine Island, or not occurring there at all. There were sixteen additional species collected on the trip, one being seen later on Ine.

Additional fertile specimens were also collected which previously had been collected only without fruit or flower on Ine Island.

In collecting information regarding local plant names care was taken to ascertain the accuracy of the informants in giving Arno Atoll names rather than names from other atolls. An attempt was made to use exclusively locally born informants. The people of Arno showed keen interest in the work and exhibited rather accurate knowledge as to localities in which each species could be found. They informed me prior to the canoe trip across the lagoon that there were a dozen more species to be found on these windward islands of the atoll, none of which was to be found on Ine Island. This was borne out in the collecting, for there were fifteen additional species which were not seen or collected on Ine.

Though only two additional species were collected on Bikarej Island, the mangrove swamp there was quite different from any seen on any other island visited. Sonneratia caseolaris was one of these two species. The other species was not a mangrove species but Portulaca samoensis, which was growing in the roadway. (Only two sterile plants were seen.) There is an aberrant form of Pemphis in the salt swamps, however. Pandanus was and still is an important food plant. Sixteen named varieties were collected on Arno Atoll and there are more varieties that were not collected. The Arno informants claimed that the seeds produced by these varieties do not produce the same variety but that the common wild variety usually results. They said it was necessary to plant a branch from the variety desired in order to increase a given variety. This seems to indicate that the varieties are merely clones. It is my opinion that there is but one species of Pandanus there and that it is Pandanus tectorius.

Breadfruit, Artocarpus altilis, also had a number of varieties. According to the informants there are six varieties of seedless and two varieties of seed breadfruit. Of the seed varieties two named varieties are easily distinguished by the leaf shape. "Mātete" variety has deeply incised leaves while "Mijwan" variety has entire to shallowly incised leaves. The initiated can distinguish the fruits by taste.

Attached is a list of species collected on Arno Atoll with Marshallese names and herbarium numbers.

Ecology

The outer shores of the windward islets are generally rougher and wider than those of the leeward islets.

The vegetation fringes of the seaward shores on the windward islets differ somewhat from those of the leeward islets. Working towards the lagoon from the sea on the windward islets the species are generally encountered in the following order: Scaevola frutescens, Messerschmidtia argentea, Pandanus tectorius, then Guettarda speciosa, Intsia bijuga, Ochrosia parviflora, Allophyllus timorensis, Terminalia litoralis, Pisonia grandis, with Polypodium scolopendria on the forest floor. In places where the shoreline is being eroded by wave action Barringtonia asiatica, Hernandia sonora, Cordia subcordata, and Calophyllum inophyllum overhang the shore.

The seaward shore vegetation fringe on the leeward islets of the atoll differs from the above pattern. Scaevola frutescens forms a nearly pure stand from the sea inland three to ten meters with scattered trees of Messerschmidtia, Guettarda, Pandanus; then these species are accompanied by Cordia subcordata, Ochrosia parviflora, and an occasional Intsia bijuga or Terminalia litoralis.

Pemphis acidula is common in areas where salt water washes across to the lagoon side at high tide. In such places they sometimes form pure stands.

In the central portion of the islets the soil improves in humus content. The soil is gray to black with varying composition of sand, coral fragments and black humus. This area is the cultivated portion as a rule. Breadfruit, bananas, papayas, "Makmok" or Tacca leontopetaloides, and coconuts are grown. Here the deep pits for growing taro are located. Two species of taro are to be found: Cyrtosperma chamissonis and Colocasia esculenta. Limes are usually found growing on the edges of the pits.

On many of the islands there are saline swamps in the central portion of the island. Clerodendrum inerme is commonly found on the margins of these areas with Bruguiera the dominant tree, though occasionally Lumnitzera littorea is associated with Bruguiera conjugata, as is the case in the easternmost end of Ine Island. Sonneratia caseolaris was also found in a saline swamp on Bikarej Islet. There were less than a dozen old Sonneratia trees seen there, growing on the side of the swamp bordering a saline lake. The opposite shore of this salt lake was fringed with pure stands of Pemphis.

The lagoon shore vegetation fringe is largely planted to coconuts; however, there are areas in which the natural vegetation still exists.

In the drier lagoon shores Pemphis acidula, Suriana maritima, and Sophora tomentosa are growing in association with Scaevola

frutescens, *Messerschmidtia argentea*, and *Cordia subcordata*. *Suriana* is found on the beach where the salt water washes the roots at high tide. It was only seen in this type of situation.

Elsewhere on the lagoon shore, *Calophyllum inophyllum*, *Pandanus tectorius*, *Terminalia litoralis*, and the same elements mentioned above are found in various combinations.

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Donald Anderson
Honolulu
30 June 1950

BOTANICAL NAMES WITH MARSHALLESE NAMES OF PLANTS ON ARNO ATOLL

Herbarium No.	Botanical Name	Marshallese Name
3761	Acalypha wilkesiana	
3615	Adenostemma lavenia	Bwilbwilikkaj
3633	Allophyllus timorensis	Kitak
3733	Alocasia macrorrhiza	Wöt
3715	Alocasia species	Wöt
3677	Amyrillis species	Kiöp (?)
3611	Angelonia salicariaefolia	Jab Meloklok
3721	Artocarpus altilis	Mā. This particular variety - Mijwan.
3678	Asclepias curassavica	Kappok, Īalo
3631	Asplenium nidus	Kartöb
3757	Barringtonia asiatica	Oob
3729	Boerhavia diffusa	Marmilliñ
3600	Bougainvillea glabra	Ikdrelel
3646	Bruguiera conjugata	Joñ
3732	Bryophyllum pinnatum	Kibilia
3767	Caesalpinia crista	Kāliklik
3706	Caesalpinia pulcherrima	Jeimata
3613	Calophyllum inophyllum	Luwej
3604	Canavalia ensiformis	Joko, Mānen, Marlap
3607	Canavalia microcarpa	Marlap
3735	Canna (indica?)	Añ
3665	Capsicum frutescens	Pepa
3673	Cardamine species	

3668	<u>Carica papaya</u>	Keinabu
3664	<u>Cassytha filiformis</u>	Kanön
3662	<u>Catharanthus roseus</u>	Ran nöñ ran
3737	<u>Ceiba pentandra</u>	Kotin
3648	<u>Cenchrus echinatus</u>	Lellik
3636	<u>Centella asiatica</u>	Madriko
3680	<u>Citrus</u> sp.	Laim
3617	<u>Clerodendrum inerme</u>	Ulej
None	<u>Cocos nucifera</u>	Ni
3682	<u>Codiaeum variegatum</u>	Krotoñ, Loimjikitok
3637	<u>Colocasia esculenta</u>	Kötak
3705	<u>Cordia subcordata</u>	Köno
3649	<u>Crinum bakeri</u> (?)	
3638	<u>Crinum macrantherum</u>	Kiöp wan (white flower)
3717	" "	Kiöp wan (flower maroon and white)
3683	<u>Cucurbita pepo</u>	Bañke
3719	<u>Cycas circinalis</u>	Lokok
3666	<u>Cyperus kyllingia</u>	
3674	<u>Cyperus rotundus</u>	Tũteoneon
3616	<u>Cyperus</u> sp.	Bũkor
3718	<u>Cyrtosperma chamissonis</u>	Iaraj
3761	<u>Dryopteris</u> dentata (sterile)	Kinen mennuel
3760	<u>Duranta repens</u>	Jab meloklok
3650	<u>Eleusine indica</u>	Katejukjuk
3601	<u>Eragrostis amabilis</u>	Ujoij

3675	*Eragrostis ciliaris* (?)	Ujoij
3640	*Euphorbia chamissonis*	Bedrol
3612	*Euphorbia heterophylla*	Nukuni
3651	*Euphorbia prostrata*	
3602	*Ficus tinctoria*	Tobro
3654	*Fimbristylis cymosa*	Drolijman
3614	*Fleurya ruderalis*	Ñëënkotkot
3622	*Gomphrena globosa*	Ebolastiñ
3685	*Gossypium barbadense*	Kotin
3641	*Guettarda speciosa*	Wut
3686	*Hedyotis biflora*	Kinoj
3734 3764	*Hemigraphis reptans*	Wut lamjen
3681	*Hernandia sonora*	Biñbiñ
3644	*Hibiscus tiliaceus*	Loo
3659	*Hibiscus* hybrid	Ros
3711	*Hibiscus* species	
3765	*Hippobroma longiflora*	Extremely poisonous (no local name)
3667	*Hymenocallis littoralis*	Kiöp in wau
3703	*Intsia bijuga*	Kuböok
3724	*Inocarpus edulis*	Kũrak
3784	*Ipomoea batatas*	Biteto
3625	*Ipomoea gracilis*	Walikok
3622	*Ipomoea tuba*	Marbele
3704	*Ixora* sp.	Kajdro

3629	*Jussiaea suffruticosa*	Wut i Lurlep
3647	*Lepturus repens*	Ujoij
3645	*Lumnitzera littorea*	Kimeme
3702	*Messerschmidia argentea*	Kidren
3687	*Mirabilis jalapa*	Emen auö
3670	*Morinda citrifolia*	Nen
3720	*Musa cavendishii*	Kȧbrañ, Binana
3728	*Musa paradisiaca*	Kȧbrañ, Binana. This particular variety-Möakadkad
3632 3626	*Nephrolepis hirsutula*	Anómkadredre
3676	*Nerium oleander*	Olianta
3603	*Ochrocarpus excelsus*	Ijoo
3640	*Ochrosia parviflora*	Kijbar
3679	*Ocimum sanctum*	Katriñ
3628	*Oplismenus* species (sterile)	Baidrik
	Pandanus tectorius (Varieties follow under this heading)	Bȯp
3689	*Pandanus tectorius* variety	Ajbwirök
3699	" " "	Allorkón
3630	" " "	Anberia
3694	" " "	Antȯklönar
3695	" " "	Benuk
3701	" " "	Bȯpiroij
3726	" " "	Bȯp in Kabiliñ
3688	" " "	Bũkor

3697	Pandanus tectorius variety	Edrwan
3690	" " "	Edwanenannelu
3693	" " "	Jabönbok
3691	" " "	Joibeb
3696	" " "	Lerro
3700	" " "	Loarme
3692	" " "	Lejokdrer
3698	" " "	Loñliñ
3766	Paspalum conjugatum	No local name known
3653	Paspalum vaginatum	Katejukjuk
3606	Pemphis acidula	Köñe
3756	Pemphis sp.	Keijor
3745	Peperomia sp.	Drebijdreke
3652	Physalis angulata (?)	Kaörör
3627	Phyllanthus niruri	Jil jino auö
3605	Pipturus argenteus	Arme
3729	Pisonia grandis	Kañal
3669	Plumeria rubra (?)	Meria
3618	Polypodium scolopendria	Kino
3656	Polyscias fruticosa	Ornamental hedge (shrub)
3655	Polyscias guilfoylei	" " "
3657	Polyscias guilfoylei var.	" " "
3658	Polyscias sp.	Large leafed hedge plant - no local name known
3624	Portulaca (lutea?)	No name known

3754	_Portulaca samoensis_	Bujon
3709	_Psilotum nudum_ (?)	Bañ
3661	_Pseuderanthemum atropurpureum_	Tiros biñ
3660	_Pseuderanthemum reticulatum_(?)	Tiros pilu
3714	_Randia graeffei_	Kielomar
3621	_Rhoeo discolor_	Kiop (?)
3712	_Saccharum officinarum_	To'o (sugar cane)
3609	_Scaevola frutescens_	Kölaeme (Purple flowered form)
3610	" "	Könnat, Marilik (common form)
3730	_Sida fallex_	Kieo
3672	_Solanum nigrum_	Name unknown. Only one plant seen.
3748	_Sonneratia caseolaris_	Bulabol
3708	_Sophora tomentosa_	Kille
3757	_Soulamea amara_	Keinwa
3608	_Suriana maritima_	Ñioñe
3713	_Tacca leontepetaloides_	Makmok
3710	_Terminalia catappa_	Kotel
3642	_Terminalia litoralis_	Kukoñ
3643	_Thuarea involuta_	Kakkũm
3623	_Triumfetta procumbens_	Atat
3614	_Vernonia cinerea_	Janailiñ Ñonailiñ
3639	_Vigna marina_	Markinejojo
3663	_Wedelia biflora_	Marjej, Markwbwebwe
3716	_Xanthosoma_ sp.	Wat in Kabiliñ (recently introduced)

3736	*Ximenia americana*	No name
3620	*Zephyranthes rosea*	No name known (small lily)
3723	Fungus - unidentified	Wutiabon̄
3734	" "	Jijabirbir
3755	Seaweed - unidentified	No name

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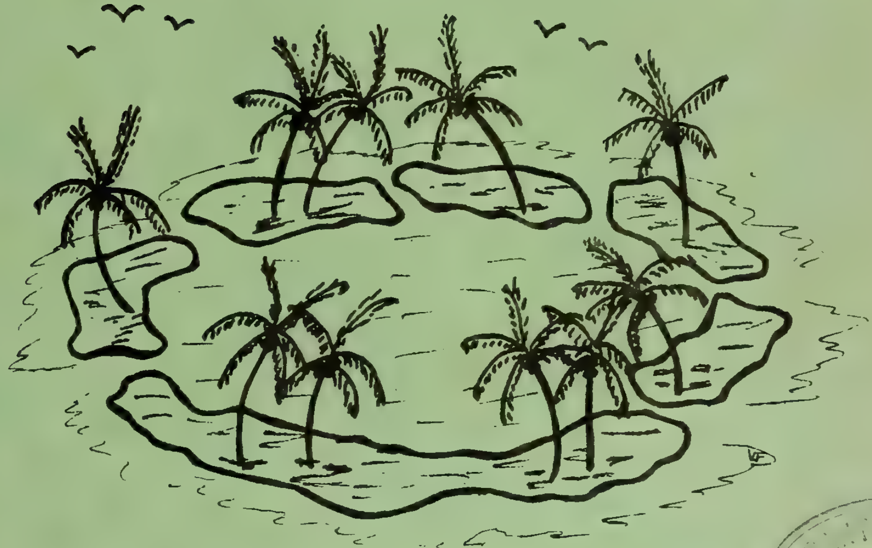
ATOLL RESEARCH BULLETIN

8. The Hydrology of Arno Atoll, Marshall Islands

9. The Coral Reefs of Arno Atoll, Marshall Islands



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It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs, CIMA, SIM, and ICCP, during the past five years. The Coral Atoll Program is a part of SIM.

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ATOLL RESEARCH BULLETIN

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8. The Hydrology of Arno Atoll, Marshall Islands

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THE HYDROLOGY OF ARNO ATOLL

MARSHALL ISLANDS

SCIENTIFIC INVESTIGATIONS IN MICRONESIA

Pacific Science Board

National Research Council

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ILLUSTRATIONS

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HYDROLOGY OF ARNO ATOLL

CLIMATE

The field investigation of the climate of Arno consisted of daily measurements of rainfall, maximum and minimum temperature, and humidity, and continuous recording of temperature and humidity. The principal weather station was at Ine Village on Ine Island on the south side of the atoll. Irregular rainfall measurements were also made on Bikarij Island and Arno Island. Due to shipping difficulties receipt of the meteorological equipment was delayed, and measurements were not started until July 2. All measurements were continued until the first week in September when the last of the party left Arno. Most of the records, therefore, cover a period of not quite two months. The Ine raingage was left in place, however, and Jokon, the scribe at Ine Village agreed to continue the daily measurements, sending the results monthly to Honolulu. As required, he will be assisted by William, the Ine school teacher.

The various measurements made so far constitute, by themselves, a hopelessly incomplete record of the Arno climate. The shorter periods of measurement will not indicate the changes even through a single seasonal cycle, and even a year's measurement of rainfall will give no indication of the limits of annual variation. However, they may be correlated with fragmentary but longer term records on the neighboring island of Majuro and with other records for Marshall Is., so that rough but useable definition of at least the hydrologic factors in the climate of Arno may be obtained.

The rainfall measurements recorded from July through November at Ine are tabulated in the appendix. The mean monthly rainfall has been 17 inches, equivalent to an annual rainfall of over 200 inches. As the record includes more summer months than winter months and as winter is reported to be the dry season, the actual annual rainfall will probably be somewhat less.

During the same period a mean monthly rainfall of 20 inches was recorded at Majuro. Most of the rainstorms are of small diameter, perhaps 10 miles across at the most. It is to be expected, therefore, that short period measurements at stations 10 miles or more away from each should show very poor correlation. Longer period totals, however, in which the effects of individual rainstorms are less important, should show greater correlation reflecting the movements of large air masses. The difference between the Ine rainfall and that of Arno, therefore, may well be a significant one. A long term estimate of the mean rainfall of Arno can probably be made when more complete records for Majuro and other Marshall Is. records become available and have been analyzed.

During a 24-day period the rainfall on Arno Island totalled 14 inches. The total for Ine for the same period was 16 inches and that at Majuro was 18 inches. This is interesting because the Arno station lies roughly between the Ine and Majuro stations yet its rainfall is not intermediate between that at Ine and Majuro but lower than either. The difference for the short period may, however, not be significant. Only four days rainfall in July were recorded at Bikarij. Afterwards the gage could not be visited until just before the party left Arno, when

it was found to be overflowing. As the total rainfall in the interim had been nearly 30 inches at Ine the overflow was to be expected, and the record contributes very little.

Daily rainfall during the period ranged from nil to over 4.14 inches. Most of this rain came in sudden intense rainstorms. No relation of rainstorm frequency to time of day was noted.

The temperature during the period of operation of the weather station ranged from 73° to 90° F. with a maximum daily range of 19° and a common daily range of 10° to 12°. The morning humidity readings ranged from 78% to 100%. The hydrothermograph records have not been analyzed, but casual inspection shows that the humidity usually dropped during the daytime, and that the humidity was generally between 80% and 95%.

TIDES

The tides of Arno were studied in some detail because of the importance of the elevation of the water table of the fresh ground-water bodies of the islands above mean sea level, and because of the importance of the tidal fluctuations in the fresh ground-water bodies of the islands. The shipping delay resulted in the loss of valuable recording time in this study also. One tide gage was established on the ocean side of Ine in the second week in July and a second was established on the lagoon side in the last week in July. The gages were kept in operation until just before the party left.

An analysis of the tide records by the Coast and Geodetic Survey indicates that the mean tide range in the ocean is 3.8 feet and the spring range is about 4.1 feet. The mean water level in the lagoon is

about the same as that in the ocean, but the mean tide range is 0.1 feet greater than that in the ocean. The explanation for this increase in tide range in the lagoon is not known.

A number of bench marks were established to facilitate leveling between tide gages and wells. Their description and elevations are listed in the appendix.

RAIN CATCHMENT

There is no runoff of the rainfall from the Island of Arno. At the most the water may run a few tens of feet on the packed surface of the main trails. Most of the rainfall seeps very quickly into the highly permeable soil. Artificial surface catchment of rainfall is, however, very important. It furnishes the entire supply of water for cooking and drinking in Ine and Arno villages and by far the major supply for those purposes generally. The best catchment structures are corregated iron roofs. In Ine Village perhaps half of the houses have such roofs, totalling about 12,000 horizontal square feet of catchment surface. Of this surface not quite 6,000 square feet is actually used, the water being led by troughs to concrete cisterns or discarded oil drums. In Ine Village there are 22 cisterns totalling about 69,000 gallons storage volume. Of these, however, only 17, totalling 53,000 gallon capacity are actually in use. With the barrels the total water storage capacity in the village is about 54,000 gallons. This is the equivalent of nearly 150 inches of rain on the tributary catchment areas. However, the ratio of the catchment areas to the capacities of the cisterns and barrels they feed is extremely variable. On the one hand some cisterns are fed only by the

roofs that cover them, and on the other some large roofs feed one or two drums. Domestic water shortages, reported recurrent during dry seasons, could probably be completely avoided if existing catchment areas were all connected with nearby existing cisterns in such a manner that the ratios of cistern volumes and repective tributary catchment areas should be as nearly a uniform as possible.

In the outlying districts the crowns of pandanus and coconut trees are used as rain catchments, the water being led by way of a prop root or a stick from the trunks of the trees, down which it runs after being concentrated by the funnels of the upper whorls of leaves, to an oil drum. Nearly every house or small group of houses that does not have a cistern on Ine and Arno Islands has one tree rigged for a rain catchment.

The rain water contained 8 to 9 parts per million chlorides at Ine during July and August. This small quantity is undoubtedly due to the solution by the rain of salt crystals resulting from evaporation of sea spray. At times of low rainfall the salinity of the rainwater may increase somewhat. It is probably higher on the windward islands than on Ine.

GROUND-WATER

The groundwater observations made on Arno can be intelligently discussed only if they are considered in relation to the shallow geological structure, and can be understood only when some of the principles of ground-water occurrence as they relate to atoll islands are known. There follows, therefore, first a discussion of shallow geological structure, second a theoretical discussion of principles of ground-water occurrence

in atolls, and third the discussion of the Arno observations as a confirmation, evaluation and expansion of the principles.

Notes on geology pertinent to ground-water occurrence

The islands on an atoll are mere heaps of sand and boulders on the "reef platform", the top of the reef that characterizes the atoll. Their position and the character of the materials within them are determined by shape, size, and exposure of the sections of the reefs on which they are developed. J. W. Wells' report on the Coral Reefs of Arno Atoll describes (p. 4) the boulder ramparts characteristically surmounting the beaches on the ocean sides of the islands. The ocean beaches themselves, though not composed entirely of boulders like the rampart, contain a large proportion of boulders and cobbles and very little fine sand. The lagoon beaches, on the south side of the lagoon at least, are composed principally of sand, much of it very fine. Because the islands are the result of accretion of beach materials, generally on both shores, the materials appearing on the beaches on the two shores of the islands should be representative of the materials composing the islands as a whole. The permeability of the coarse ocean-beach sediments should expectably be much higher than that of the fine lagoon-beach sediments.

Wells also describes the beach rock commonly exposed along the shores. In this material, whether derived from sand or beach gravel, the original pores and very largely filled with cement so that the permeability is very low.

The small dashed lines in diagrams A and E of the accompanying figure indicate the depths at which gravel and hard rock were encountered under the sand as indicated by wells along two profiles across Ine Island. The

lower small dashed-line represents the top of well consolidated rock, either as seen in the bottom of large wells, as exposed on the surface, or as estimated from the limit to which drivepoints could be simply churned down, or the top of gravel exposed in wells or on the surface. The long dashed line represents a projection of the reef surface beneath the islands.

It will be noted that under the narrow part of the island shown in diagram A, there is no consolidated rock above the level of reef platform except on the lagoon beach where there is beach rock. This section was drawn across a canoe portage where a channel had been washed out across the island in a hurricane. The beach rock extended on surface only to the west edge of the portage and was found by probing to extend only part way across the portage, so that a few feet east of the section shown there was no beach rock. The whole section of the island except for the face of the lagoon beach and a small lagoon beach ridge or dune were composed of coarse sand and gravel.

In the wider part of the island there is apparently hard rock to two or three feet above the level of the reefs but not above mean sea level except where beach rock was formed on the ocean beach. This hard rock might represent merely boulders too large to crack with the drivepipe under most of the wells, but it was evidently a continuous layer under well B. No beach rock was exposed on the lagoon beach at this section, and there is room for only a very narrow beach rock zone at the most between the beach surface and well P.

The structure and texture are not so obvious in the underlying reef as are in the overlying sediments. It will be noted in Wells' discussion

of reef zonation (pp. 11-16) that along the south side of Arno Atoll the lagoon reefs are covered with extensive patches of sand that are absent or at least not prominent on the ocean reef. Whether the surface conditions are typical of the underlying materials depends on whether the present environments are typical of those prevailing while the reefs were being built. Unfortunately our knowledge of the history of coral reefs is so slight that there is no general agreement as to the conditions of their development. All that can be said, therefore, is that there appears to be a possibility for the development of asymmetry in the permeability of the reef itself. As will be shown in the analysis of the ground-water measurements such asymmetry apparently obtains under Ine Island.

Principles of ground-water occurrence on atoll islands

Most of the rainfall on atoll islands, all that is not caught on and evaporated from the plants and the surface of the ground, seeps quickly into the ground. A part of this seepage is held in capillary openings in the soil and remains available to shallow-rooted plants. In most regions of the world this soil water is the most important source of water for plants, which withdraw it and transpire it to the atmosphere. It is undoubtedly a very important source on atoll islands and probably the main source for many plants, but the low ground elevations probably permit other plants to obtain water also from a deeper accumulation to be discussed.

The excess beyond the capillary capacity of the soil generally filters down through the sand to a foot or so above sea level, where it joins and maintains a body of more or less fresh water saturating the

rock and sand. From this body of what may be called basal ground-water it may be lost by withdrawal and transpiration by deep-rooted plants, by withdrawal from wells, and by underground flow laterally to the shorelines, both ocean and lagoon.

Salt water is denser than fresh water. Providing a volume of fresh water is somehow confined so that it cannot mix with the salt water, it will float on salt water, displacing the salt water just as a lump of ice or a stick would. The densities of fresh water and ocean water of usual salinity are such that approximately one unit of fresh water above the ocean water level will be supported by every 40 units below. A porous rock, partly submerged in ocean water, though it does not absolutely confine the water that saturates it, provides a restriction of flow that may reduce mixing sufficiently so that if fresh water is introduced into it, an integral body of fresh water will be maintained, floating on the salt water in the rock with its surface 1 foot above the level of the salt water for approximately every 40 feet of depth of fresh water below the salt water level. This principle, known as the Ghyben-Herzberg law after its first discoverers, applies in coastal areas, including islands, underlain by porous rocks in many parts of the world. Fresh water introduced by rainfall forms a basal fresh-ground-water layer whose depth below sea level is approximately 40 times the head or elevation of its water table above sea level.

It is a well established principle, called Darcy's law, first that the amount of ground water flowing through a sand of given cross section will be proportional to the hydraulic gradient, which, in a ground-water

body with a water-table that is not too steep, may be measured by the loss in elevation of the water table per unit distance measured in the direction of flow, and second that with the same hydraulic gradient in the same system but with sands of different sizes and degrees of compaction the amount of water flowing through a given cross section will be proportional to a factor called the permeability of the sand, which may be thought of as merely its capacity to transmit the water. Doubling the cross-sectional area, doubling the hydraulic gradient, or doubling the permeability of a system will double the rate of flow of water through it.

Disregarding the water withdrawn from wells, negligible on most atoll islands, the excess of rainwater introduced into a basal ground-water body of the Ghyben-Herzberg type over the amount of water withdrawn by plants from the body can be lost from the body only by flow to its margins at the shores. This flow can be induced only by a hydraulic gradient toward the shores, and by the Ghyben-Herzberg law the higher heads inland must be balanced by greater depths of fresh water inland. Assume for a moment that the permeability is constant and the rainfall, or rather its excess over transpiration and evaporation, is uniform both in space and time. Through the shore edges of the fresh water body all of the rainfall excess over the whole island must be flowing. Yet the head is low near the shore, and the thickness of fresh water small. By Darcy's law, the combination of high rate of flow and small cross sectional area must be balanced by a high shoreward hydraulic gradient, and rapid increase of both head and depth of fresh water inland. In sections of the island nearer to the center the head and depth of fresh water are

greater, and the amount of rainfall excess, being the part derived from the central part of the island only, is less. The hydraulic gradient must be smaller, and the rate of increase of head and fresh-water thickness inland is smaller. The fresh-water body, therefore, has a lenticular shape with a bow-shaped water table that is convex upward and with a lower, salt-water contact that is similarly but exaggeratedly convex downward.

In any island of uniform permeability the maximum head and thickness of fresh water will be greater if the rainfall is greater, smaller if the rainfall is less. If the rainfall is not uniform but varies seasonally there will be a seasonal change in the head and thickness of fresh water. Even the effects of daily variation in rainfall may cause variation in the head, although the effects of short term variations will lag behind the original variations and are not as great as the effects of long term variations of the same amount. The lag and damping are even greater in variations in the depth of fresh water than in variations in head.

In two islands of the same size and rainfall, the one with the lower permeability will have the higher head and the thicker fresh-water lens. In two islands of dissimilar size but having the same permeability and receiving the same rainfall, the larger island will have the higher head and the thicker fresh-water lens. Because of the change in shapes of the fresh water lens with change in size, the relationships of rainfall rate, island size, and permeability to the thickness of the fresh water lens are complicated and not those of direct proportionality.

The sea level, which controls the position of the fresh-water lens, is, of course, not constant but has tides. The loss of water from the

fresh ground-water lens is, therefore, controlled not by a constant base level but by a variable one; the hydraulic gradients throughout the lens and the rate of loss are, therefore, variable. As a consequence, the altitude of the ground-water table itself is variable, showing a tidal fluctuation much like the oceans but smaller and with a time lag. The lag and the degree of damping of the tide in the fresh water body are dependent on the distance from the coast, the permeability and depth of the aquifer, and the porosity of the section alternately saturated and drained. The greater the distance, the smaller the permeability and depth of aquifer, and the greater the porosity, the greater are the tidal damping and lag.

Fresh water resting upon salt water in the open will, of course, quickly mingle with the salt by diffusion and by mixing through turbulence accompanying any wave motion. In the medium of a permeable rock the rate of mingling is greatly reduced. Diffusion becomes an unimportant process, and there is no ordinary wave motion except at the extreme margins of the lens. However, the tidal movement of the lens and the alternate swelling and shrinking of the lens by increases and decreases in the rate of recharge, as compared to loss by withdrawals by plants and flow to the sea, result in raising and lowering of the salt-fresh contact. As the contact is raised, some fresh water is left in the rocks below the contact to mingle with the invading salt water, and as the contact is lowered some salt water is left above to mingle with the fresh. Consequently, the contact is not a sharp one but a gradual transition.

Where the spread of salt water into the fresh-water zone is larger than the downward component of the movement of the fresh water in response to recharge, the zone of mixture will extend clear to the top of the lens,

and if the rate of mixing is large enough or the recharge small enough, the water even at the top of the lens may be too brackish for drinking, or even for utilization by most plants. Sea water contains roughly 2 per cent chloride ions (equivalent to about 0.2% NaCl). Drinking water should preferably contain no more than 0.03 per cent chlorides and certainly no more than 0.1 per cent, or one twentieth the amount in sea water. The rate of movement of salt into and up through the fresh-water zone is dependent on the amount of climatic and tidal fluctuation of the theoretical salt water-fresh water boundary, on the vertical salt-content gradient, on the nature of the porosity (the mixing effect probably being heightened in material of variable pore size), and on the vertical component of the salt-content gradient (the transfer of salt being most rapid where the change in salt content with depth is highest). At the center of an island the tidal fluctuation is at a minimum, and the depth of fresh water is at a maximum, so that the rate of salt transfer is at a minimum, and there may be a low salt content and comparatively little change of salt content with depth near the top of the Ghyben-Herzberg lens. Near the coast the tidal range is greater in the ground-water body, and the total depth of fresh water is less, so that the salt gradient is steeper and the freshest water more brackish. At the shore the tide range is at a maximum and the depth of fresh water is at a minimum. Furthermore, at high tide there is a reverse hydraulic gradient carrying salt water into the island. Consequently all of the water emerging at the shore is brackish, and the change in salt content with depth and time is complex.

The average salinity at any point in a Ghyben-Herzberg lens in a small island is, therefore, complexed controlled by the size of the island,

the horizontal location of the point on it with reference to the coast lines and the vertical location of the point in the lens, by the average recharge (that is the average excess of rainfall over transpiration and evaporation losses) and by the variability of the recharge, by the permeability and porosity of the rocks, and by the tidal range in the surrounding water. The salinity at the point may be at a particular time greatly different from the average salinity at the point. Near the surface of the lens, except at the shore, the salinity will depend principally on the time elapsed since the last rainfalls and the magnitudes of those rainfalls in relation to the porosity and permeability. Soon after a rain the salinity will drop fairly quickly and then return gradually to a normal value which will be determined, like the salinity deeper in the lens, principally by seasonal changes of recharge, again with relation to the permeability. As has been already indicated, the salinity at the shore will be greatly influenced by the tides.

In the discussion so far, the rocks of the island have been assumed to have uniform permeability. That this assumption is unrealistic has been shown for Ine Island in the preceeding section, and the consequences of some of the expectable variability of permeability will be discussed here.

The difference in origin and texture between the reef problem and the islands on top of it constitutes perhaps the major source of a possible difference in permeability, but the permeability of each is highly variable, and no offhand guess can be made as to which has the larger overall permeability. If, on the other hand, the reef platform has a considerably lower permeability than that of the sediments of the overlying island, the

Ghyben-Herzberg principle might apply so far as the depth of the fresh-water lens, but the part of the fresh-water body in the island sediments would function very nearly as if it were an independent body on an impermeable layer. The tidal response would be considerably less than if the reef platform had equal permeability, but the fluctuations of head with variations in rainfall would be much greater. There would be much less opportunity for mixing, and the ground-water would be much fresher. If, on the other hand, the reef platform were much more permeable than the island sediments the system would function very much as if it were uniformly as permeable as the reef platform.

The predominance of boulders, cobbles, and coarse sand in the ocean beach and the predominance of fine sand in the lagoon beach suggest strongly a greater permeability in the oceanward parts of the Ine Island than in the lagoonward parts. This difference may apply in other islands. The difference in wave intensity on the two sides of the reef may result in making one side of the reef platform more permeable than the other. The effects of asymmetry in the permeability of the reef platform should be much more important than those of asymmetry in the permeability of the overlying sediments. Any asymmetry in the distribution of permeabilities would result in a lower water table, a thinner fresh-water layer, a greater tidal effect, and a greater salinity on the high permeability side than on the low permeability side.

The beach rock found on both ocean and lagoon shores is much less permeable than the uncemented sediments. Where there is beach rock at the shore, either on the surface or buried under new sand, it should serve as a barrier to outflow of the fresh water. If the reef platform is permeable

the effect of this barrier should be small, but if the reef platform is impermeable the beach-rock barriers might serve almost like the sides of a tank, effectively sealing off the fresh water from the ocean and causing a high head, very little tidal effect, and low salinity.

Beach rock related to old shore lines and buried now in interior parts of the islands might make similar barriers within the islands resulting in the separation of two or more independent fresh-water bodies if the reef platform were impermeable. Such layers of beach rock might also result in the perching of thin bodies of fresh water above sea level.

Ground-water observations on Arno

The accompanying diagrams summarize the most important part of the observations on ground-water conditions on Ine Island. The ground-water conditions are shown across the island at a point east of Ine Village where it is nearly 1400 feet wide and at a point west of Ine Village where it is only a little more than 300 feet wide. The conditions can best be discussed as they confirm, evaluate and expand the previously discussed principles of ground water occurrence.

The relationship between the head and the distance from the shorelines is shown by diagram A, a cross-section of the wide part of the island with a great vertical exaggeration. Three water-table positions are shown, the upper and lower being the tidal limits of the water table and the middle one being the mean position. Each slopes continuously toward the shorelines from a high point about a third of the way from the lagoon to the ocean shore, except where high-tide water table slopes inland for a short distance at each shore and also slopes toward the lagoon for a short distance near the center of the island. The probable

explanation for these deviations will be discussed shortly. The variation in mean head with distance from shorelines is shown with still greater vertical exaggeration by the two solid lines in diagram C. The heavier of these lines shows elevations of the mean water table for one day above long-term mean sea level. The lighter line indicates elevations of the mean water table for the same day above the mean sea level for that day. The latter line is probably more directly meaningful, because the heads may be expected to be very largely adjusted to tides of periods longer than a day.

Diagrams E and G indicate that the head at the center of the narrower part of the island is less than the head in the wide part of the island shown in diagrams A and C. Diagrams E and G do not show well the shape of the water table because there was only one measuring point in the narrow section of the island.

Diagrams B and F indicate the undistorted theoretical shapes of the Ghyben-Herzberg lenses in the cross sections of the wide and narrow parts of the island respectively. The depths of the lenses have merely been computed from the heads above mean sea level for the day on which they were measured, assuming that the heads were fully adjusted to long period tides. The lower limits shown may be regarded as the approximate levels of water half as saline as ocean water. Much of the water above these levels is too salty for humans or even plants to use.

That there is a greater effective permeability on the ocean side of at least the wide part of the island is indicated definitely by the relatively low head inland from the ocean shore and relatively high head inland from the lagoon shore as shown in diagrams A and C. The same asymmetry

in permeability probably exists in the narrow section too, but cannot be proved with only the one central measuring station.

The difference in permeability is also indicated by the greater damping and lag of the tides as they move in from the lagoon shore than as the move in from the ocean shore. In the tidal graphs, diagrams D and H, the damping and lag of the two principal tidal components, semi-diurnal and diurnal, are shown separately. Consideration of the tide as a whole would result in confusion, because the periods of the components are effective as well as the characteristics of the aquifer in determining the damping amd lag, and the two components do not, therefore, behave as a unit as they move into the aquifer. The quantity a/x is a parameter describing the tidal progression as a whole and the values plotted were averaged from values obtained from both phase lag and damping effects in both semi-diurnal and diurnal components.

Attention has already been called to the landward slopes of the near-shore parts of the water table at high tide. Such a reversal of slope is expectable in most Ghyben-Herzberg lenses discharging without restraint to the sea. Because of the large range of the tide at Ine as compared to the maximum head the ocean and lagoon levels are actually nearly three feet higher than the highest part of the ground-water table at high tide. Because of the lag in the inland progression of the tide, the two lines representing the high- and low-tide limits of the water table do not re-present two respectively contemporaneous positions of the water table. At times of high tide in the ocean the tide in the ground-water body is still rising toward the high-tide limit shown, and the landward slope is even more extreme than is shown. The lagoonward slope of the high-tide water

table near the center of the island probably results from the ground-water in the high permeability, oceanward part of the island acting itself like the sea in controlling the discharge of the ground-water from the low-permeability, lagoonward part of the island. This behavior suggests a rather sharp discontinuity in the permeability near the center of the island.

As a result of the lower head and greater tidal fluctuation in the oceanward part of the island than in the lagoonward part, the water at the top of the lens is freshest in the lagoonward part of the island, as shown by the dashed line in diagram C which represents the salinity of samples drawn nearly simultaneously from the several wells across the wide part of the island and plotted on a logarithmic scale. The water in well S contained 8 ppm. chlorides, the same concentration as in the original rainwater, and an amount astonishingly low to anyone accustomed to the range in salinities to be found at far greater distances from the sea in the Ghyben-Herzberg lenses of volcanic islands like Hawaii. Water of 250 ppm. chlorides or less could be found within 70 feet of the lagoon shore but not closer than 750 feet from the ocean shore, and water of 1000 ppm. chlorides within 60 feet of the lagoon shore but not closer than 400 feet of the ocean shore. The salinity at the center of the narrow part of the island at the same time was 5500 ppm. as shown in diagram G, indicating the very great importance of the width of the island on the minimum salinity in the Ghyben-Herzberg lens.

The permeability of the near-surface sediments may be estimated from the hydraulics of the shallow wells and from the characteristics of the material, that of the zone occupied by the Ghyben-Herzberg lens may be estimated from the gradients of the water table, and that of the much deeper

zone affected by tidal flow from the tidal lag and damping. The theories linking permeability with these various measurable effects are, unfortunately, poorly worked out, but the rough approximations possible provide some very useful results. The water-table gradients on the two sides of Ine Island indicate an effective permeability ten times or more greater in the zone occupied by the Ghyben-Herzberg lens on the ocean side than on the lagoon side. The permeability coefficients computed for this zone are much greater than those expected in the kinds of sediments found near the water-table, indicating that the reef platform must be a permeability discontinuity below which the permeability is greater than above. The tidal effects indicate that the high permeability continues to a depth greater than that of the Ghyben-Herzberg lens.

These observations, with a number of scattered observations of tidal fluctuation, salinity, and hardness of water not fully worked up yet, indicate that on the wide parts of the islands of Arno Atoll, and probably on wide atoll islands with a similar climate generally, there is a well developed Ghyben-Herzberg lens with a maximum head of about a foot above mean sea level containing fresh water in its upper part. The highest head and freshest water is to be found toward the side of the island under which the average permeability is lowest, which on Ine and Arno at least, and probably very commonly, is the lagoon side. Toward the ocean side the lower head and a greater tidal fluctuation result in greater mixing of the fresh water with the underlying salt water.

Seasonal changes in ground-water

The field observations on Ine were all made during the rainy season in the Marshalls. The heads measured should, therefore, be expected to be

near the maximum to be found during the year, and the salinities measured, therefore, near the minimum. It seems certain that the patterns of head and salinity differences over the width of an island will not differ significantly at any season from that noted, but the amount of decrease in head and of increase in salinity cannot at present be predicted. Monthly measurements of head in a key well are being maintained through a year by the scribe of Ine, so that considerably more information will be available on this point. The data received so far will not be listed here, because they have not yet been corrected for tidal effects and are useless until so corrected.

Native reports indicate that the salt content at the freshest wells on Ine and Bikarij rises enough to be noticeable but not enough to make domestic use of the water impossible.

Utilization of ground-water

The Marshallese draw directly only a small quantity of ground-water. There are no wells in the densely populated part of Ine Village, and the whole water supply there comes from rain catchment. In the more rural areas of both Ine and Arno there are a number of dug wells used almost entirely to supply water for washing clothes. Even where there are wells, the water used for other purposes is rain water. In view of the probable ease of biological contamination of the ground water under such a low, previous terrain, the failure to use much ground water for drinking is probably fortunate. Two of these wells sunk in comparatively high ground were lined with blocks of beach rock. Most were sunk in low places and lined with oil drums with the ends cut out, two oil drums, one on top of another, being used in some. Oil drum wells were seen also on Bikarij by Squires. None of the wells extend more than a couple of feet into the water.

Besides the wells used for wash water there are a number of pits excavated to a foot or two below the water table for use in retting coconut husks. The husks of copra nuts are merely piled in these pits, covered with leaves and trash, and allowed to decompose for a few months, after which the fibers are easily separated for use in making cordage. There is apparently no important salinity control on the retting process, some of the retting being done in pits excavated in the beaches or merely in piles covered with rocks on the beaches. The retting pits in the interior of the islands are apparently located there merely to be convenient to the source of nuts.

The small direct draft of ground-water is no indication of the overall importance of the water that seeps into the ground. As has already been discussed, the water in the unsaturated part of the soil is probably primarily responsible for supporting the heavy vegetation of wet atolls like Arno, but some of the plants are wholly or partly dependent on ground-water from the saturated zone.

Conscious use is made of ground-water in taro culture by the Marshallese. The wet-land forms of taro will grow only in soils saturated with water, and also, it is believed in Hawaii, only where the water is in movement. With no surface streams, the Marshallese have been able to meet the requirements by excavating pits from the surface of the ground 5 or 6 feet or more deep, penetrating the water-table. Taro is grown in organic muck, accumulated by rotting vegetation in these pits. The surface of the muck is generally at about mean water-table, so that water stands in the pits about half the time. The tidal fluctuation of the water-table apparently induces sufficient movement of the water. The area

occupied by taro pits on Ine Island corresponds to the distribution of the freshest ground-water in the lens, that containing 20 ppm. or less of chlorides at the time of sampling. The taro pits on Arno Island occupy a corresponding position, undoubtedly because of the same control. Taro is known in Hawaii to be rather intolerant of salt.

Ground-water apparently plays an additional important part in sustaining breadfruit trees. Breadfruit is not generally regarded as a phreatophyte (plant utilizing ground-water from below the water-table) and on high islands it is clearly not a phreatophyte. However, the distribution of productive breadfruit trees corresponds so closely with the pattern of salinity of the ground water that some ground-water control seems certainly effective. It is possible that the control is exercised only during the dry season when vadose water (that held in the unsaturated soil above the water-table) is inadequate to maintain growth, or itself reflects the salinity of the underlying ground water due to capillary rise. In general, the breadfruit trees are limited to a zone including the taro pit zone and extending beyond to a position corresponding to perhaps 200 to 400 ppm. chloride content in the underlying water at the time of sampling. There are a few breadfruit trees growing on Ine Island seaward of this limit, and a few on Arno that probably are also. None of these seaward trees are as large as many of the trees in the center and lagoonward parts of the islands, and it is noted by the Marshallese that they fail to bear or are at best poor bearers. There are no breadfruit trees on narrow parts of the islands. It should be remembered that the limits of a few tens of parts per million chlorides for taro and a few hundreds for breadfruit are wet-season limits. Undoubtedly the dry-season limits representing the real control are considerably higher.

The distribution of settlements and roads, close to the lagoon shore on nearly all of the islands of Arno Atoll, is probably very closely the result of the breadfruit and taro distribution.

Banana and papaya trees show distributions similar to that of taro, but more limited, probably as a result of limiting plantings close to settlements. No other economically important plants seem to be limited by the availability of fresh ground-water.

APPENDIX

Rainfall measurements on Arno Atoll

1950

day	July Ine	July Arno	July Bikarij	August Ine	August Arno	August Bikarij	Sept. Ine	Oct. Ine	Nov. Ine
1				0.50	–	–	0.44	0.54	0.77
2				1.60	1.30	–	1.17	tr	0.07
3				2.52	0.91	–	0.11	0.50	0.40
4				0.58	tr	–	?	0.51	0.39
5				0.00	0.81	–	0.82	0.55	4.56
6				0.57	0.17	–	2.40	1.25	0.45
7				tr	0.35	–	2.10	0.05	0.01
8				0.27	0.09	–	0.55	1.90	tr
9				0.37	2.26	–	1.66	0.24	0.03
10				0.66	0.21	–	0.34	1.17	0.64
11	0.07			0.10	0.18	–	0.89	0.87	0.48
12	0.35			0.91	0.93	–	0.27	tr	0.00
13	0.32			0.30	0.02	–	0.01	0.00	0.00
14	0.17		0.30	1.26	tr	–	0.02	0.00	0.00
15	0.03		0.23	1.21	0.68	–	1.16	0.14	tr
16	0.23		0.11	0.81		–	0.31	0.47	0.00
17	0.43		0.92	0.06		–	0.17	0.00	0.31
18	1.77		–	0.80		–	0.50	0.02	0.08
19	1.24		–	0.27		–	2.77	0.08	0.23
20	0.77		–	0.12		–	0.23	1.10	0.61
21	1.01		–	0.31		–	0.57	0.54	0.25
22	tr		–	0.03		–	0.59	0.09	0.00
23	tr	0.07	–	0.18		–	0.07	0.61	0.00
24	0.39	0.78	–	0.22		–	0.01	2.07	0.12
25	1.36	0.98	–	0.87		–	0.01	0.44	1.88
26	2.42	1.24	–	0.27		–	0.48	0.10	0.49
27	0.47	0.41	–	0.19		–	0.57	0.02	0.54
28	0.50	1.81	–	0.09		–	tr	2.11	0.03
29	0.00	0.66	–	0.55		–	0.00	0.61	0.14
30	0.00	–	–	4.14		–	0.14	0.91	0.00
31	0.03	–	–	0.59		overflowing		0.64	
Total	11.56[a]	6.05[a]	1.56[a]	20.35	7.91[a]		18.36	17.53	12.49
	17.10[b]								
Mean	0.55			0.66			0.61	0.57	0.42

tr Trace

– Not read. Rainfall included in succeeding reading.

? No record. May be incorporated in succeeding days' catch.

a Incomplete.

b Estimate based on partial record.

Bench Marks at Ine Village

Bench mark 1:

The top of head of galvanized spike driven into north side of coconut palm tree about one foot above ground. Tree is nearest to ocean on southeast side of trail leading to beach from point on main trail about 75 feet northwest of northwesternmost houses of Ine Village, and about 450 feet northwest of main trail intersection at church.

Elevation: 8.71 feet above mean sea level at Ocean.

Bench mark 2:

A small cowrie shell filled with cement and set into top of unused concrete foundation post on south corner of concrete platform around house on north corner at trail intersection at church.

Elevation: 8.27 feet above mean sea level at Ocean.

Bench mark 3:

A circle chiseled in beach sandstone on lagoon beach at foot of trail leading lagoonward from church.

Elevation: 4.39 feet above mean sea level at Ocean.

Bench mark 4:

A circle chiseled on edge of east corner of concrete cistern, 30 feet northwest of trail from church to lagoon a point 125 feet from intersection at church.

Elevation: 6.74 feet above mean sea level at Ocean.

Bench mark 5:

A circle chiseled in south corner of concrete foundation of northwest concrete post at entrance to Ine Council House.

Elevation: 8.80 feet above mean sea level at Ocean.

Bench mark 6:

A circle chiseled in northwest side of concrete sill around Iroij Well, about 140 feet south of main trail at point 75 feet southeast of Council House.

Elevation: 8.14 feet above mean sea level at Ocean.

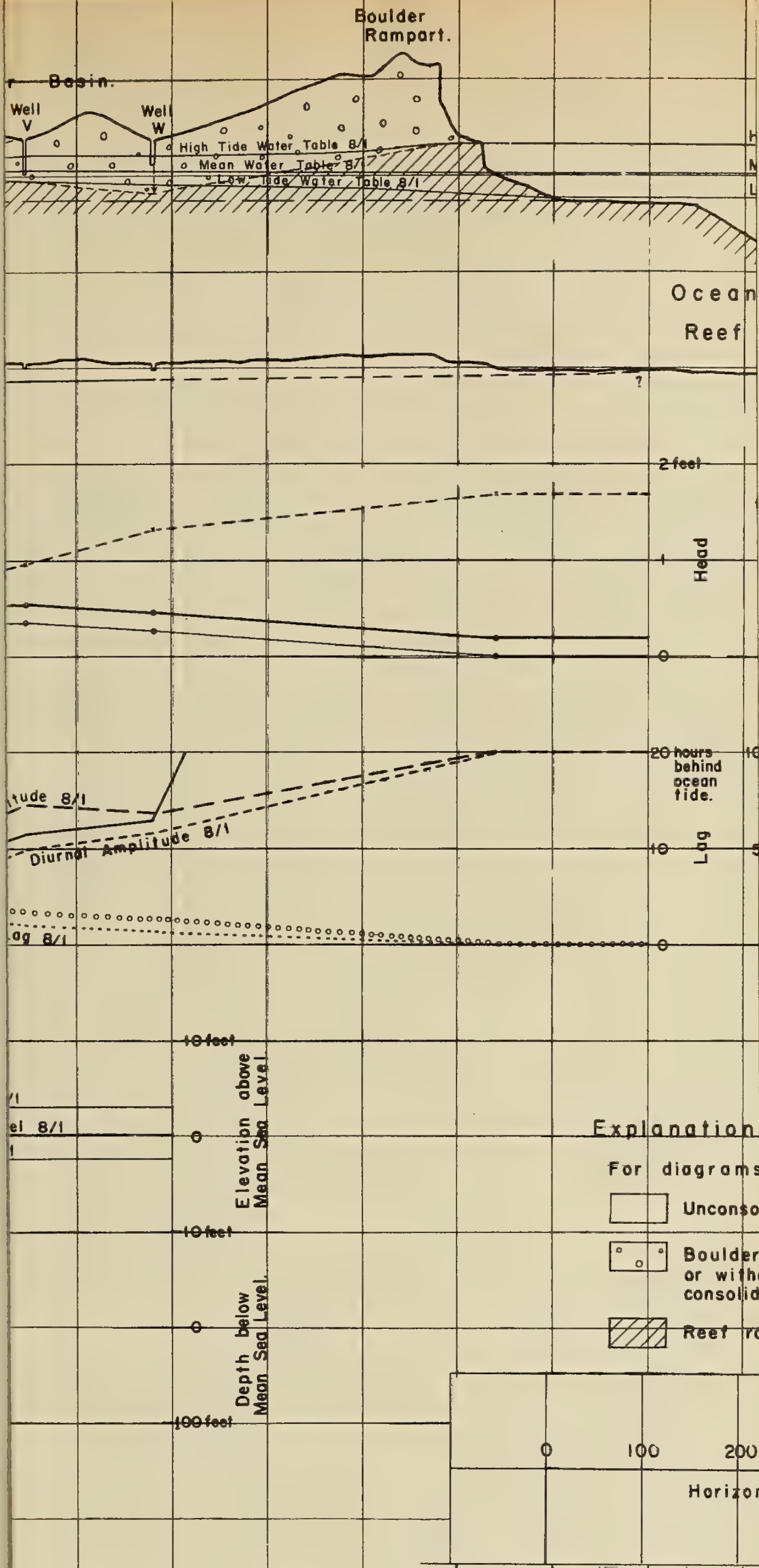
Bench marks established July 1950. Mean low water elevations and reduction to mean sea level at ocean computed by U. S. Coast and Geodetic Survey.

Tidal data for Ine Island

All elevations referred to mean sea level in ocean.

	At ocean	At lagoon
Mean high water	1.90	1.93
Half tide level	0.00	-0.02
Mean sea level	0.00	----
Mean low water	-1.90	-1.97
Mean low water springs	-2.75	-2.82

Mean low water elevations and reduction to mean sea level at ocean computed by U. S. Coast and Geodetic Survey.



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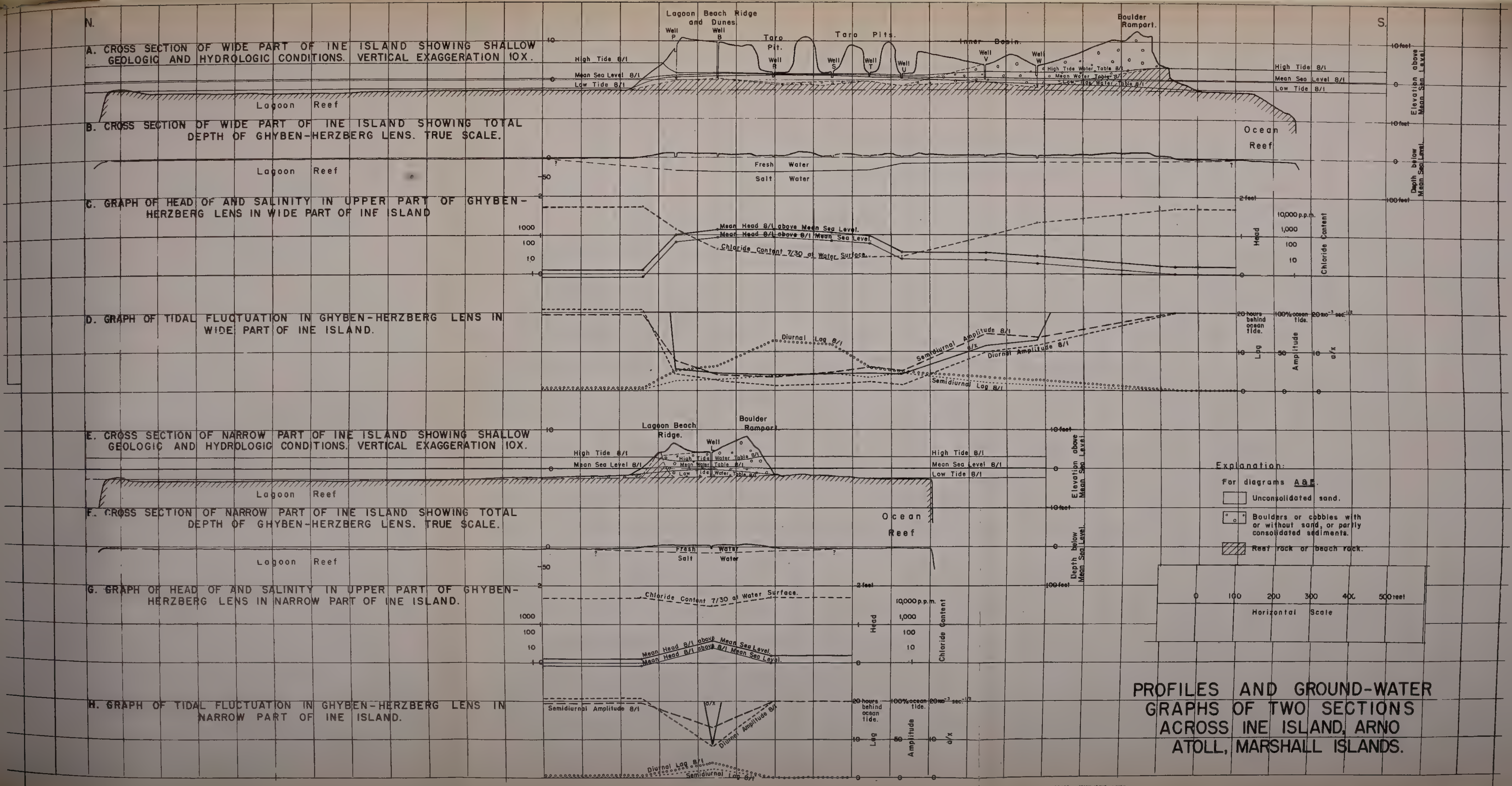

PROFILES AND GROUND-WATER GRAPHS OF TWO SECTIONS ACROSS INE ISLAND, ARNO ATOLL, MARSHALL ISLANDS.

ATOLL RESEARCH BULLETIN

9. The Coral Reefs of Arno Atoll, Marshall Islands

Issued by

THE PACIFIC SCIENCE BOARD

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Washington, D. C.

December 15, 1951

THE CORAL REEFS OF ARNO ATOLL,

MARSHALL ISLANDS

SCIENTIFIC INVESTIGATIONS IN MICRONESIA - Pacific Science Board

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An atoll has a top that's flat
And featureless extremely.
Corals and algae make a mat
Where mountains are not seemly.

(R.H.F., 1949)

John W. Wells
Cornell University
December 1951

ACKNOWLEDGMENTS

The author of this report participated in the 1950 SIM (Scientific Investigations in Micronesia) Project of the Pacific Science Board of the National Research Council. This project was supported by funds granted to the National Academy of Sciences by the Office of Naval Research, and the field work was carried out with the active assistance of the Navy Department, the Military Air Transport Service, and the officials of the Civil Administrative Staff of the Trust Territory (Navy).

To all of the above who helped to make possible the research described in this report I wish to express my gratitude and appreciation.

Special thanks are due to Mr. Donald F. Squires (Cornell '50) without whose able assistance in the field much less would have been accomplished.

CONTENTS

FIGURES

I. Field Work

A. Reefs

The coral reefs were the main object of study during the field period, and all types of reefs represented at Arno were investigated in more or less detail:

Ine Island - Seaward-leeward reef; windward-lagoon reef. A three-mile stretch on either side of Ine Village was mapped in detail on a scale of 1:8000.

Takleb Island - Seaward-windward reef; leeward-lagoon reef. Mapped.

Aotle and associated islets - Seaward-windward reef; lagoon reef. Mapped.

East Horn (Malel to Lonar I.) - Seaward-windward reef; lagoon reef (enclosed lagoon). Mapped.

North Horn (Eneman-Bikarej-Namwi) - Seaward-windward reef; seaward-leeward reef; enclosed lagoon reef; reef "dam" at north end. Mapped.

Studies were made of the water temperature fluctuations on the reef tract on the seaward side of Ine Village.

B. Lagoon

Following the arrival on 19 July of dredging gear from Washington, dredging was carried out nearly every day until 1 August, when the gear was re-packed for shipment. Earlier attempts to dredge with a crude dredge made from material at hand produced results, but were less than satisfactory. The regular dredges were more successful, but the great difficulties in operating from sailing outrigger canoes emphasize that systematic dredging, a necessary part of any scientific study of an atoll, is possible only from a sizeable powered boat. Nevertheless, as a result of Mr. Squires' persistence, a number of bottom samples and zoological specimens were obtained from some 25 hauls in the lagoon, even though nearly half of them were dry runs.

C. Collections

Corals. About 600 specimens, mostly cured, of reef and lagoon corals were collected.

Other. Insofar as possible, with only 2 gallons of alcohol, specimens of mollusca, echinoderms, alcyonarians, foraminifera, crustaceans, etc., were collected for the U.S. National Museum, as well as some dried material. A number of specimens were preserved but later had to be discarded or dried because of lack of sufficient preservative. Ten gallons of alcohol requested from Majuro late in June was finally delivered at Majuro on the return journey.

Some was added to the one tank, but the rest by that time was of no use and was returned.

In all 18 wooden packing cases were filled, weighing about 1000 pounds and shipped back by surface transport. The corals are still being studied, and a complete list at this time is impractical, but it is estimated that over 100 species representing about 45 genera of scleractinian and hydrozoan corals were procured, with ecological data. A list of these genera is appended.

About 350 photographs (Kodachrome) were taken, mostly of reef phenomena, including a number of underwater views. Five hundred feet of 16-mm. color motion picture film were exposed, again mostly of reef features above and below water, with unexpectedly good results. The motion picture camera and tripod were a loan from the Navy through the Honolulu office of the Pacific Science Board, and grateful acknowledgment of this is here made.

II. Structure and Physical Processes

A. General Statement

Arno Atoll, in the southern Marshall Islands at approximately 172 deg. E. and 7 deg. N., lies in the northeast trade wind belt and in the north equatorial current. The latter is deflected northwards during the summer months by the equatorial counter current. It is in that part of the Pacific where the surface water temperatures do not fluctuate more than 1 deg. above or below 28 deg. C. - the warmest part of the Pacific. The temperature, clarity, and agitation of the surface are at the optimum for reef coral development, but the planktonic food supply, on the other hand, despite the seasonal reversal of oceanic currents, is lower than in areas farther to the southwest and coral growth is below the maximum.

Arno, like many atolls, departs from the common idea of circular atoll shape, being roughly rectangular with two extensions or "horns", one extending to the north about 5 miles from the north corner of the rectangle ("North Horn"). The other extends about 7 miles northeastward from the east corner ("East Horn") (Figs. 1 and 2). Both horns are peculiar in that each encloses near its tip a small secondary lagoon separated from the main atoll lagoon. The total area enclosed by the seaward reefs and lagoons is about 147 sq. mi. The surface reefs cover about 16 sq. mi. and on them 133 islands and islets form about 5 sq. mi. of dry land. The main lagoon encloses about 125 sq. mi., the secondary lagoon in the East Horn about 4.5 sq. mi., while the little enclosed lagoon of the North Horn has an area of only 1.5 sq. mi. (Fig. 4). The seaward reefs extend continuously around the entire atoll, except where they are broken by Tutu and Takleb Passes, which have threshold depths (15-25 fms.) nearly equal to the lagoon depth, three shallow (4 fms or less) passes east from Takleb and one shallow pass into the northwest part of the East Horn lagoon. The total peripheral extent of the seaward reefs is about 65 miles, and except for minor pass into the East Horn lagoon, all breaks in the reef are in the 6-mile windward stretch of the northeastern face of the atoll extending southeasterly from Tutu Pass toward Namej Island.

The seaward slopes (Fig. 3) of the outer reefs are steeper to leeward than to windward. No precise data are available, but it is obvious from an inspection of aerial photographs of Arno, and indicated by H.O. Chart 6005, that there is a decided difference. At Ine Anchorage a depth of 200 meters is reached about 150 meters out from the reef margin, a slope of 55 deg. At 1700 meters the depth is 1000 meters, about 27 deg. Thus the profile from reef edge seaward is concave and steeper near the reefs, and gentler with increasing depth. On the seaward side to windward off Takleb Island the depth 400 meters out from the reef edge is only 40 meters, a 7 deg. slope. In the next 350 meters the depth increases to 200 meters, a slope of 25 deg., nearly the same as the downward slope from 200 meters on the leeward side. At 3500 meters from the reef margin a depth of 1000 meters is reached, a slope of 19 deg. from 750 meters. This slope is essentially convex near the reefs, thence gently concave. The presence or absence of a 10-fathom terrace like that at Bikini is not determined, but comparison of aerial photographs of corresponding parts of the two atolls suggests strongly that it is developed on the windward side of Arno.

The material of which the reef and islands of Arno is composed is wholly coral reef limestone and its derivatives: boulders, cobbles, pebbles, sand, and finer silt-size particles. Small patches of phosphatic limestone occur in the interior of a few of the larger islands, but rock material other than limestone is very rare and accidental. Early in the 19th Century Chamisso noted that the natives in the Radack chain (eastern Marshalls) searched the beaches for stranded tree trunks with tough rocks tangled in their roots, for tools. Stranded trunks from North America are actually not uncommon on the Arno beaches, presumably carried in by the California and North Equatorial Currents. Two in particular were noted in 1950, one a huge cut fir log 5 x 55 feet, the other a redwood trunk in the roots of which were several sizeable chunks of a tough quartzitic grey-green sandstone. The only other stray "foreign" rocks on Arno are bits of pumice ranging in size from small pebbles to rounded pieces the size of one's head, found both high on seaward and lagoon beaches and inland.

B. Structure of the atoll islands. (Fig. 5).

The beaches of the seaward sides of the atoll are everywhere bordered, with very few exceptions such as Ine Anchorage and stretches of low reef tract on which islands are not yet developed, by boulder ramparts. These are ridges of boulders and cobbles of water-worn coral carried by storm waves from the outer slope and ridge of the reef over the reef flat. The rampart is 6 or 7 feet high on leeward sides of the atoll, but to windward it is often as much as 10 or 12 feet.

Boulder ramparts or ridges are the first stage in the development of islands. In their lee accumulate finer materials, stray boulders, pebbles and sand, carried over the ramparts and around their crescentiform ends, spread out on a gentle slope toward the lagoon. Where the rampart is fairly stable, chinks between the larger pieces become filled in with sand and pebbles from the beach zone, and between tide-marks it may be consolidated by cementation into solid strata of beach conglomerate with initial dip toward the reef flat to which it is welded. Beach conglomerate is often exposed where a slight shift in wave approach removes loose surface material and stands with the

rampart as the second line of defence behind the reef margin.

Where the seaward reef flat is broad the inner part near shore may be covered by a rubble tract or sheet of large irregular coral blocks to a thickness of as much as 3 or 4 feet. Since they lie between tide marks, these sheets may here and there be consolidated into a tough horizontal stratum. All gradations from fresh, more or less angular rubble through rubble conglomerate to old conglomerate, corroded and decayed to the point of being mere remanants more or less stoutly welded to the reef flat, can be seen.

The beaches around islands are relatively narrow, 3 to 4 feet high, and lie between low tide level and the highest point ordinarily reached by the waves at high tide. Their slope is adjusted to the normal wave action in their area. On seaward side of islands they are steep and narrow, with slopes up to 20°. On lagoon sides they are wider with slopes of 5°-10°. A few inches beneath the surfaces of most sand beaches bordering the lagoon are patches of beach sandstone with initial dip corresponding to the beach slope, developed as a result of cementation between tide marks, and often welded by their lower edges to the reef flat. Beach sandstone, like beach conglomerate, is an important factor in anchoring islands to the reef.

Another structural feature is the sand dunes developed on the lagoon sides of some islands where there is a sand beach facing the wind. The strong trades sweep over the beaches exposed at low tide and move particles of sand 0.2-0.7 mm. in size up the beach and drop them at the top, in much the same manner as dune are built on other windward shores elsewhere. The dune sand is composed of more uniformly-sized particles than beach sand. The dunes form more or less continuous ridges 2 to 5 feet above the top of the beach. Behind them the island surface slopes gently toward the interior of the island where the wind-carried sand mingles with the material spread in the opposite direction from the boulder rampart. Such a dune ridge extends almost continuously the length of Ine Island. In places it is double, the outer one being lower and newer than the inner one. At one point, about a mile east of Ine Village, the ridge is nearly 15 feet above the beach (Arno's mountain) and 50-100 feet broad.

The interiors of islands are 6 or 7 feet above low tide level, and consist of more or less horizontal layers of material derived from the seaward boulder rampart and lagoonward dune ridge or beach, often more or less consolidated into island or cay sandstone.

Figure 5 shows a generalized cross-section of an island on the lee side of Arno Atoll.

In summary: the islands and islets represent constructional work of wind and wave with materials derived from the living reefs. They are accumulations of loose material partly held together by a patchwork "endoskeleton" or framework of beach conglomerate to seaward, beach sandstone lagoonward, and interior island sandstone. They are seen in all stages of development on Arno, from lonely little bits of rampart with a single sprouting coconut to broad islands sufficiently old to have small patches of phosphatic limestone in their interiors. They are not, at least on Arno, as some would have us believe, the remains of old reef flats raised above sea-level by the more or less recent 5 or 6-foot lowering of sea-level coincident with the accumulation of the Greenland and Antarctic icecaps. Evidence of this eustatic shift is supposed to be widespread in the Pacific but no features at Arno need be ascribed to it. Speculation that the

old reef surface elevated by eustatic change has been completely planed away at Arno seem unnecessary. Emphasis by some observers that isolated masses of reef rock welded to the present reef flat is evidence of an older, now elevated reef flat overlooks the possibility suggested here that they are remnants of old cemented rubble tracts.

C. Surface processes and changes.

Everywhere on Arno evidence can be seen of moderate change due to shoreline processes, and here and there vast changes due to occasional great typhoons. The former are more obvious on the lagoon side, the latter on both lagoon and seaward sides, and both are most apparent on the lee side of the atoll.

The thirteen-mile long lagoon shore of Ine Island has a nearly continuous sand beach. In places this beach is being aggraded, as at Ine Village. Some of the slow sand increment is carried in from the lagoon reef flat, and some is shifted along shore by waves from another part of the beach. From Ine Village westward for some miles stretches of gravel-cobble beach alternate with stretches of beach sand. The gravel beaches develop in places where waves are strong enough to degrade, leaving concentrations of coarse material. This alternation coincides with the alternately concave and convex parts of the reef and island with respect to the lagoon. Degradational gravel beaches occur along the salients, aggradational sand beaches in reentrants. The lagoon reef is not yet wide enough to stabilize the shoreline - the geomorphologists' Nirvana, a shoreline of equilibrium, is far from reached.

Active degradation of a sand beach is seen at the east end of Ine Island, where for the last few miles the beach is narrow and the dune ridge is strongly undercut so that turf overhangs the top of the beach. Coconut palms have toppled onto the beach in an almost even row and are slowly dying. About a quarter mile west of Ine Village, approaching a convexity in the island, undercutting has proceded so far inland that the dune ridge has almost disappeared and a 3-foot cliff of island sandstone is now being cut into. At this site the island is unusually narrow, less than 100 feet, and the initiation of the present slow undercutting is the result of washing away of most of the dune ridge and old beach sandstone by typhoon waves. The beach sandstone that lay under the old beach is now exposed at the water's edge at low tide.

More striking, however, than the normal shoreline changes, are the effects of the typhoons that strike the Southern Marshalls four or five times a century. Records are rare and older natives are the only source of eyewitness information, but their recollections are naturally vivid of such disasters and are confirmed by the physical traces of typhoon effects which can still be seen. One old man, Lijömmar, remembers four typhoons during his lifetime, those of 1905 and 1918 being the last two, as he related to Dr. E. L. Stone in 1950. These are remembered by others and their dates seem fairly certain. That of 1905 was the most violent.

Previous to 1905, according to Lijömmar and others, all of the islands now scattered along the reef from the eastern tip of Ine some 18 miles to L'Angar Island at the tip of the East Horn were one continuous island, with only one canoe passage (portage?) between the west end of Ine and L'Angar, apparently

apparently a mile or so north of the present east end of Ine (Fig. 7,A). The typhoon of 1905 swept away long stretches of this island (Fig. 7,B) so that where there was a single long island there are now about 40 (Fig. 7,C), the smaller ones having been built up since the typhoon, the larger ones being remnants of the original island. Confirmation of this extensive change is found on a small chart, corrected by officers of the old "Albatross" from a German hydrographic chart, published in 1903 by Alexander Agassiz (M.C.Z. Harvard, Mem., vol. 28, fig. 4, p. 228), which shows a continuous strip of land from L'Angar to the west end of Ine, broken by a pass near the present east end of Ine and another about 5 miles west of Ine Village. If these passes existed, they must have been merely canoe passes over the reef, or possibly portages, for no break in the reef can be seen at or near these places on aerial photographs, and Agassiz himself did not see them, saying "....there are said to be several boat passes on the southwestern face of the lagoon." At any rate, two years after the corrected chart was published, it was obsolete.

The destructive effects of typhoons on atoll islands can be seen at many places on the leeward side of Arno. Mention has been made of the washing away of a stretch of lagoon beach just west of Ine Village, exposing island and beach sandstone. About 2 miles farther west beyond Jab'u, the island narrows to less than a third of its normal width and in places is scarcely 30 feet wide (Fig. 8). For half a mile the dune ridge is very much lower and between it and the boulder ridge on the other side of the island the sand seems to have been scooped out into miniature box canyons with steep heads toward the rampart. About 50 feet from the beach remnants of the old beach sandstone can be seen at low tide on the lagoon reef flat, indicating the former greater width of the island. This change was the result of water piled up on the leeward side during the 1918 typhoon washing completely over the island into the lagoon, carrying away land, dune, and lagoon beach. Since then a new beach, underlain by freshly-formed beach sandstone, and a new dune ridge have developed. Similar washouts were seen at the east end of Kilange near the base of the East Horn. On the next island west, Malel, are large numbers of prostrate breadfruit trees, still alive, which were downed by the same storm.

Eastward from Ine Village extend two old paths bordered by beach sandstone slabs, one paralleling the lagoon beach, the other swinging south and paralleling the seaward shore just inside the boulder rampart. Beyond Stony Point, as one approaches the next "point", the beach swings inward crossing the trend of the path which ends abruptly as if cut off. For several hundred yards beyond, the southern part of the island has apparently been carried away by a typhoon to the extent that on the next point the old island sandstone core is now exposed at the edge of the reef flat.

The 1905 typhoon washed away parts of the former long island between L'Angar and Ine and left long stretches between with only the bare bones of former land, -- a low ridge of beach sandstone on the lagoon side, a rubbly band in the former island interior and a new seaward boulder rampart (Fig. 6). Over the lagoon reef opposite these places are strewn masses of rubble, now corroding, the finer materials having been bypassed into the lagoon. Dark lines of old beach sandstone, marking the site of former beaches and land, show well on aerial photographs and can be traced nearly continuously between islands from L'Angar almost to Ine. The amount of land lost during this typhoon on this part of the atoll was about 160 acres, only 5% of the total land on Arno now, but nearly 25% of the area of the former island.

Typhoons and destruction of land on Arno will occur again and again. The forces tending to construct new land are slowly but steadily operating, but in the 46 years since the last great storm, they have not replaced the land lost then. It has not been possible to determine how many of the small islands in the area of major destruction are remnants and how many are replacements, but certainly less than 10% of the lost acreage has been made up. The typhoon of 1918 probably destroyed part of the gain, and that of 1950 may have washed away still more. The long narrow islands of Arno invite typhoon damage, for they act as barriers to the heightened tides and waves of the storm, and the only egress for the piled-up waters is over the land.

From these observations it would appear that the windward side of atolls in the Southern Marshalls are safer and less susceptible to damage than the leeward. Typhoons in this region come from a southerly direction and the normally leeward side bears the brunt of the shock. The leeward reef, its islands, and the lagoon absorb and weaken the rush of water, and waves in the lagoon can hardly rise as high as the open sea waves. The windward islands suffer mainly from the high winds instead of being overwhelmed by water during a great storm. Unfortunately, most of the land on Arno is on the lee or typhoon weather side.

Little, if anything, can be done directly by man to lessen, much less prevent, loss of land or soil by typhoon damage. This should be kept in mind if attempts are ever made to increase soil productivity on atoll islands. Greater soil productivity leads not necessarily to higher or better standards of living, but to larger populations. Well-intentioned attempts to improve the lot of the native populations of atolls thus might well jeopardize more lives than ever when the inevitable typhoon sweeps in, and lead to appalling drops in population and lower living standards than now obtain for the survivors. True, the Indian Ocean atoll of Cocos-Keeling has been almost completely devastated several times in the last century by typhoons and still comfortably supports a very much denser population than any Pacific atoll. But Cocos has capital wealth obtained from other sources than the atoll soil and is populated by a highly energetic group of people under a strong patriarchy.

D. Reef types.

The seaward reefs at Bikini Atoll in the Northern Marshalls were recently classified by Tracey, Ladd, and Hoffmeister (1948, G.S.A. Bull., vol. 59, p. 870), largely on the basis of the character of the reef margins, as follows:

I. Strongly grooved.

- A. Lithothamnion ridge low, uncut by grooves.
- B. Lithothamnion ridge prominent, cut by grooves.
  1. Room and pillar structure developed.
  2. Algal mounds and blowholes developed.

II. Grooves weak or absent.

- A. Margin smoothly scalloped.
- B. Margins made irregular by erosion.
  (two subtypes)

The distribution of these types at Bikini is shown on Figure 3 of the paper cited. Application of this classification to the Arno reefs is shown in Figure 2 of this report. Comparison of the two shows one striking difference and a number of similarities. The difference is the almost complete absence of reefs of Type II, in which the grooves down the upper part of the slope are weak or absent, at Arno, whereas at Bikini they are characteristic of the leeward stretches. According to Tracey, Ladd, and Hoffmeister, where reefs of this type are developed there is no evidence of a terrace. At Arno there is no evidence of a terrace on the leeward slopes, but a strongly grooved, steeply sloping reef margin of Type IA, with low algal ridge, is developed. A typical profile of such a leeward reef of this type at Arno is shown in Fig. 9.

Reefs of Type IB_2, with strongly developed algal ridge, are found at corresponding windward sites at both atolls, alternating with Type IA which is developed on stretches less exposed to the northeasterly and easterly trades. At Arno there does not appear to be the close relation between islands and Type IB reefs and stretches between islands and Type IA, observed at Bikini. In areas where there are islands or islets on the reef, open spaces between islands are narrow and water flow across the flat is impeded by rubble.

At only one site at Arno is a reef of Type II (grooves weak or absent) developed. A stretch of about 300 meters northwestward from Stony Point on the seaward leeward side at Ine Anchorage in a shallow bay between two crescentiform swellings of Ine Island best fits Type IIA. Grooves are absent and the margin slopes very steeply, practically vertically at first, less so below about 10 meters, with an average slope of 55 deg. to 200 meters. There are more or less regular re-entrants 3 to 10 meters deep, 2 to 10 meters wide, with sandy or rocky floors. One or two of these are interconnected by open channels, isolating flat-topped pillars, but there is no evidence of collapse due to erosion. Wind waves are negligible at this site and the strong swells from the east are reduced by the projection of Stony Point.

E. Lagoon Reefs

The lagoon reefs are not so continuously developed as the seaward reefs although banks on which reefs might exist are continuous. They are best developed along the windward lagoon side of the west, south, and north sides, where there is little or no wash of sand and other detritus from the seaward reefs. The only development of leeward lagoon reefs on the windward side of the atoll is in the vicinity of the two threshold passes, Tutu and Takleb. The sand banks developed on the lagoon side of the windward reefs from wash from these reefs are rapidly extending into the lagoon. They slope steeply downward toward the lagoon floor at about 35 deg., the normal angle of repose.

In the enclosed lagoons of the North and East Horns the reefs are distributed as in the main lagoon but again coral growth is patchy owing to the sand cover of the flats and lagoon slopes.

In the North Horn (Fig. 4), which has no pass whatever to seaward a special situation has developed. On all sides except the north, the seaward reef flats are built up either with islands or thick rubble to a level above low tide level. On the eastern side the rubble areas between islands are penetrated by sand-floored channels from the lagoon side, usually with a moderately rich growth of corals, but about halfway to the seaward margin they become very shoal and choked

by rubble which often is more or less cemented. Except to the north this rim is 1 to 2 feet above low tide level, but is 2 to 3 feet below high tide level. When tide level falls below the rim level the excess water flows northward and part of it escapes over the lower rim between the ends of the windward and leeward reefs. The rest of it flows outward through the channels onto the seaward reef flats. Formerly most of the excess flowed out by the northern outlet, which was covered or crossed by a reef flat built to within about a foot of low tide level. This rapidly moving water, however, supported a profuse growth of corals and calcareous algae which have now grown up across the opening, forming a low, broad, convex rampart, one edge of which slopes steeply into the lagoon, the other gently down into the scattered microatolls around the embayment in the northern end of the horn. At present this dam has a uniform crest of at least 2 feet above low tide level on the seaward side, and over its entire surface there is a steady but diminishing outflow of water as the tide ebbs. Coral growth is rich but the depth of water on the spillway slope at each low tide is now hardly more than an inch and broad stretches are exposed, and coral colonies are low and spreading. Thus the water level in the enclosed North Horn lagoon never falls as low as the level reached at low tide on the seaward reefs.

This enclosed North Horn lagoon is much shallower than the main lagoon or the enclosed East Horn lagoon, and soundings shown on the H.O. chart indicate a maximum depth of 10 fathoms. Coral knolls are numerous, and the lagoon is probably filling rather rapidly. Because of the absence of even a shallow pass into this lagoon circulation of the lower levels of water in it must be restricted, but unfortunately it was not possible to obtain bottom samples bearing on this point.

F. Coral Knolls.

These characteristic structures of atoll lagoons, often loosely referred to as "coral heads", are abundant in all the Arno lagoons (Figure 1 shows only a very few of the knolls). Some of them are sufficiently developed as to be awash or even exposed 2 to 4 feet at low tide. In the main lagoon there are six areas where they are concentrated: 1) in the area at the base of the North Horn generally west of Eneweto Island, 2) a large cluster fanning out from the break in the reef south of Jarkul Island, 3) across the inner end of Tutu Pass, 4) halfway across the lagoon between Takleb Pass and Ine Village, 5) in the southeast corner of the lagoon, and 6) in the secondary embayment at the base of the East Horn.

The distribution of the knoll clusters seems less than fortuitous. Three are in corners of the lagoon, and two are associated with threshold passes. The remaining one, the large Jarkul cluster, is probably also of the second group. The broad break in the reef southeast of Jarkul (2 miles northwest of Tutu I.) suggests a filled-in threshold pass. The absence of a strong seaward reef at this point still enables the wind waves and swells to sweep in and transport large quantities of sand which are building a "delta" into the lagoon over the site of the former pass. Around this "delta", within a radius of about 1.25 miles there are at least 65 knolls visible on aerial photographs in addition to two large shoals. The cluster around Tutu Pass is smaller - 22 - and none is visible in the immediate vicinity of Takleb Pass. The latter is shallower than Tutu and less to windward, but the large cluster in the lagoon to the south, beginning about a mile from the pass, may be related to it. Are these knoll clusters related to the developmental stage of the passes with which they are associated?

A somewhat similar distribution of knolls may be found in the lagoon of Majuro Atoll, suggesting an interesting minor research problem.

III. Reef Zonation

A. Seaward Reefs

As indicated above, three reef types of the Tracey-Ladd-Hoffmeister classification are developed at Arno: IA, IB, and IIA.

1. Type IA.

This is the dominant type at Arno, and extends almost uninterruptedly from the west side of the North Horn southward around the lee side of the atoll to the eastern end of the East Horn. A typical section of this type of reef, strongly grooved with a low algal ridge uncut by the grooves, is shown in Figure 9. The broad rock flat, seemingly barren, supports no coral growth except in occasional depressions where small patches of Porites lichen and a few other forms grow feebly. At practically all sites, however, except on open stretches unbroken by development of islands (i.e., NE of Kilomon, E. of Takleb), there is an extensive overgrowth of a curly, disreputable-looking brown alga (Micro- n okamurai) on the fronds of which live vast numbers of Calcarina. Associated with these are many individuals of the large, closely-adherent pelecypod Chama which resemble projections of rock about the size of one's fist. This is the Calcarina-Chama zone. This zone is truly barren only where there are prominent convexities in the reef (Fig. 8). Where this flat begins to slope gently down as the "algal ridge" toward the upper ends of the grooves, low and broadly adherent colonies of Pocillopora are usually dominant, (with fewer specimens of Acropora, Astreopora, Porites, etc.), on the weak encrustation of lithothamnion,- the Pocillopora zone, at the outer end of the waves of translation at low tide. Beyond this, in the surf zone, Pocillopora is replaced by Acropora (A. pectinata, A. digitifera, etc.), forming a zone extending well down into the upper part of the grooved area. Other common genera in the Acropora zone are: Astreopora, Porites, Millepora, Favites, etc.

2. Type IB.

This seaward reef type, with relatively high, prominent algal ridge, is characteristic of the exposed windward reef tracts, and is replaced by Type IA only where some protection is afforded by concavities in the reef margin. The usual zonation of this type is shown in the section, Figure 10. The rocky flat is usually less richly endowed with the alga-Calcarina-Chama association and the ridge is not a place of vigorous coral growth. The surge channels are usually shallow, rarely roofed over, and often partly filled with coarse boulders. Occasional small colonies of Acropora cuneata are found, but less commonly than in the corresponding zone on reefs of this type at Bikini. Nowhere is this reef as broad as at Bikini, and no trace of an inner Heliopora zone was noted.

3. Type IIA.

As previously noted, this type is found only in a limited area at Ine Anchorage (Fig. 8). It is distinctly zoned by corals as shown in the section, Figure 11. Following an inner barren zone, exposed for long periods at practically

every low tide, is a broad tract thickly settled by extensive colonies of Montipora ramosa, -- a nearly exclusive society, here and there replaced by patches of Acropora hebes or alcyoniid "soft corals"(Lobularia). Occasional colonies of Synaraea, Leptastrea, Porites (especially P. superfusa), and Pavona, also occur. At low tide the depth is from zero to about fifteen inches, and the water is practically undisturbed by swells or waves of translation. The outer limit of this zone is at about the inner extent of the ordinary low tide waves of translation, where it is succeeded by a zone dominated by Acropora, especially species of the corymbose A. pectinata type, which extends to the reef margin. Fungia scutaria is common in this zone. It is the zone of richest variety of corals and other reef animals. Calcareous algae are relatively very unimportant. Species of at least 33 genera of scleractinians and hydrozoans have been collected in the zone, but Acropora accounts for around 90% of all colonies. Over the reef edge and in the re-entrants along the edge the next zone, marked by the pedestal colonies of A. reticulata, begins about 6 feet below low tide level in water only slightly agitated by the constant but low swells, and extends down to about 30 feet, where coral growth becomes very sparse. Fungia scutaria, F. fungites, and F. concinna are very common.

B. Lagoon Reefs

Two main types of lagoon reefs may be distinguished at Arno. One is found on the leeward side of reef tracts on the windward side of the atoll, or on the leeward side on long stretches where islands are not yet developed. The other is developed on the windward side of the island-flecked reef tract on the leeward side of the atoll.

1. Leeward Type.

The first type is developed in the enclosed lagoons of the North and East Horns (Fig. 13), and in places along the sheltered leeward side of the reef tract between the horns (Fig. 12). The immediate substratum is primarily the sand washed into the lagoon margin from the outer reefs, either across the flats or around the passes. These sand tracts slope steeply (35 deg.) at their inner edges, which may be from a very few to several hundred feet out from the shore, down to the lagoon floor. On this insecure base luxuriant coral patches are scatteringly developed, rising with more or less abrupt sides from depths of a foot or so, often very close to the beach, to 12 or 15 feet. The spaces between them are flat and floored with sand on which few corals grow. The characteristic coral of this zone is Porites andrewsi, a ramose form found in the same environment at Bikini and other northern Marshall atolls. Also common in this zone is Acropora palifera which often forms huge colonies in shallower parts of the sandy interspaces. Fungia is common. The Acropora reticulata zone, found below about 6 feet on the Type IIA seaward reef, extends as might be expected on these protected lagoon reefs well into the P. andrewsi zone, in as little as 2 or 3 feet of water at low tide. It does not appear to extend downward much below about 20 feet.

2. Windward Type

The second type of lagoon reef at Arno, exemplified by the section, Figure 14, extends from near the southeastern corner of the lagoon along the windward southern side of the lagoon the entire length of Ine Island to Arno

Island, about 13 miles, and beyond. It is the broadest of Arno reefs of any type, averaging about 1500 feet from beach to margin. The flat consists of a patchy veneer of sand and silt on an uneven, corroded reef rock flat which lies from 6 inches to 3 feet below low tide level. It is shallower near shore, deepening to about 3 feet at the midpoint, then shoaling near the margin, which in a few places is exposed at low tide. Beyond this low ridge the rock surface, often quite bare of sediment, slopes gently at about 10 deg. to the sandy floor of the lagoon at 15 or 20 fathoms. Coral growth over this type of reef is sporadic and nowhere rich and flourishing. The width and depth of the tract enable the wind waves to proceed well in toward shore where they keep the sand and silt well stirred at high tide, inhibiting the growth of all but a few colonies of such hardy forms as _Porites lutea_ and _Pocillopora damicornis_. _Hippopus_ is common in this inner zone. In the deeper water beyond and nearly to the margin, _Astreopora_ is abundant, forming massive heads up to 5 feet across. Many large dead colonies of _Acropora palifera_ and _A. gemmifera_, occasional large Pocillopora, and discouraged _Porites andrewsi_ also occur. On the bare, pitted and irregular marginal slope is found the widest variety of forms, but no one species appears dominant. Especially common are several species of soft alcyoniid corals (_Lobularia_ and _Lobophytum_). _Fungia_ is absent. Lithothamnion is only occasional and not flourishing. From a depth of about 5 feet down the slope, _Acropora reticulata_ is dominant, often forming huge spreading brackets 3 to 8 feet across. This zone extends nearly to the lagoon floor into the _Acropora formosa_ habitat.

A third type of lagoon reef, with an algal ridge and zonation similar to that of seaward reefs, is developed at Bikini around the western end of the lagoon, where wind waves developed over a fetch of about 20 miles produce a strong surf. This type is not found at Arno where nowhere do prevailing winds have a fetch of more than 10 miles.

IV. Reef Temperatures

For mid-Pacific reefs there is, so far as the writer is aware, only one detailed record of water temperature variations across a definite reef tract. In 1918, A. G. Meyer published (Carnegie Inst. Wash., Pub. 213, pp. 31-34, fig.9) an account of the temperatures on the Maer Island coral reef, Torres Straits,—a fringing reef about 188 feet wide. In general he showed that while daily temperature changes at the seaward margin have a narrow range (3.5 deg. C.), the range increases toward shore to as much as 12.5 deg. (C.), and concluded that the high temperatures experienced during part of the year must be sufficient to kill all corals within 450 feet of the shore.

During the month of June, 1950, a number of temperature traverses were made across the Ine Anchorage Reef along the section line of Fig. 11, at various times of day and states of tide. The temperatures were measured at the height of coral growth, usually about a foot from the bottom, at 30-foot intervals across the 450-foot width of the reef. The results are summarized in the chart, Figure 15 and presented in the same form as Mayer's cited above. On the basis of Mayer's results and theoretical considerations, the results obtained at Arno might have been predicted. The least range is found at the seaward edge, the greatest nearest shore, regardless of the state of the tide. Coral growth on the reef is closely correlated with this. It is richest at the reef margin where the temperatures are more constant, and weakest or absent near shore where temperature ranges are greatest. This correlation, of course, is not exclusively due to

temperature control. Agitation and water movements are greatest near the edge; salinity fluctuations due to heavy rainfall are greatest in the very shallow water near shore, among other controlling factors.

The fluctuation is diurnal. Early in the morning, before the sun shines on the reef flat, temperatures across the reef are nearly uniform, usually a degree less nearer shore than the normal 28 deg. C. at the reef margin, but within a few hours temperatures near shore, even at high tide, are much higher than at the margin.

Of particular interest are the two sets of serial temperatures graphically analyzed in Figure 16. These were run at 50-foot intervals along a line 1000 feet long and parallel to the reef edge and about 200 feet from shore, approximately on the boundary between the Acropora and Montipora zones. At the east end this line cuts across the transverse section line of serial temperatures shown in Figure 15. At high tide (10:30 a.m., 24 June) the water along this line was about 3-4 feet deep, and little variation in temperature was expected or found. With this depth of water the swells are little impeded and broken by the reef margin and no cause for fluctuation is developed. But at low tide (4:00 p.m., 23 June) great variation was found: from 28.2 to 30.9 deg. at more or less regular intervals along the tract. The highs were about 200 feet apart and alternated with the lows. These represent wedges of cooler water extending into the shoreward band of warmer water, or contrawise. The separation of these wedges is striking. At one spot a temperature difference of 1.5 deg. was found in a distance of only 25 feet.

The explanation of these wedges of warm and cool water at low tide is not hard to find. There is a close correlation between the wedges and the re-entrant channels in the reef margin. The cooler water wedges are opposite the re-entrants, the warmer wedges extend outward opposite the salients. At low tide the constant swells from the southeast, refracted around the easterly side of the atoll from the northeast, are slowed by the salients but move undiminished into the re-entrants. A wave of translation forms at the head of a re-entrant and is reinforced by refracted swells from the salient on either side. This drives a mass of cooler water onto the reef flat at each re-entrant. Rip currents moving outward onto the salients then shift the displaced warmer water toward the salients.

V. Appendix: List of Coral Genera Occurring at Arno

A. Scleractinia

Acanthastrea
Acrhelia
Acropora
Alveopora
Anacropora
Astreopora
Coscinaraea
Culicia
Cyphastrea
Echinopora
Favia
Favites
Fungia
Goniastrea
Goniopora
Halomitra
Herpolitha
Hydrophora
Leptastrea
Leptoseris
Leptoria
Lobophyllia
Merulina
Montipora
Mycedium
Pavona
" (*Polyastra*)
" (*Pseudocolumnastraea*)
Platygyra
Plesiastrea
Pocillopora
Porites
" (*Synaraea*)
Psammocora
" (*Plesioseris*)
" (*Stephanaria*)
Seriatopora
Stylocoeniella
Stylophora
Symphyllia
Ulophyllia

B. Alcyonaria

Heliopora
Tubipora

C. Hydrozoa

Distichopora
Millepora
Stylaster

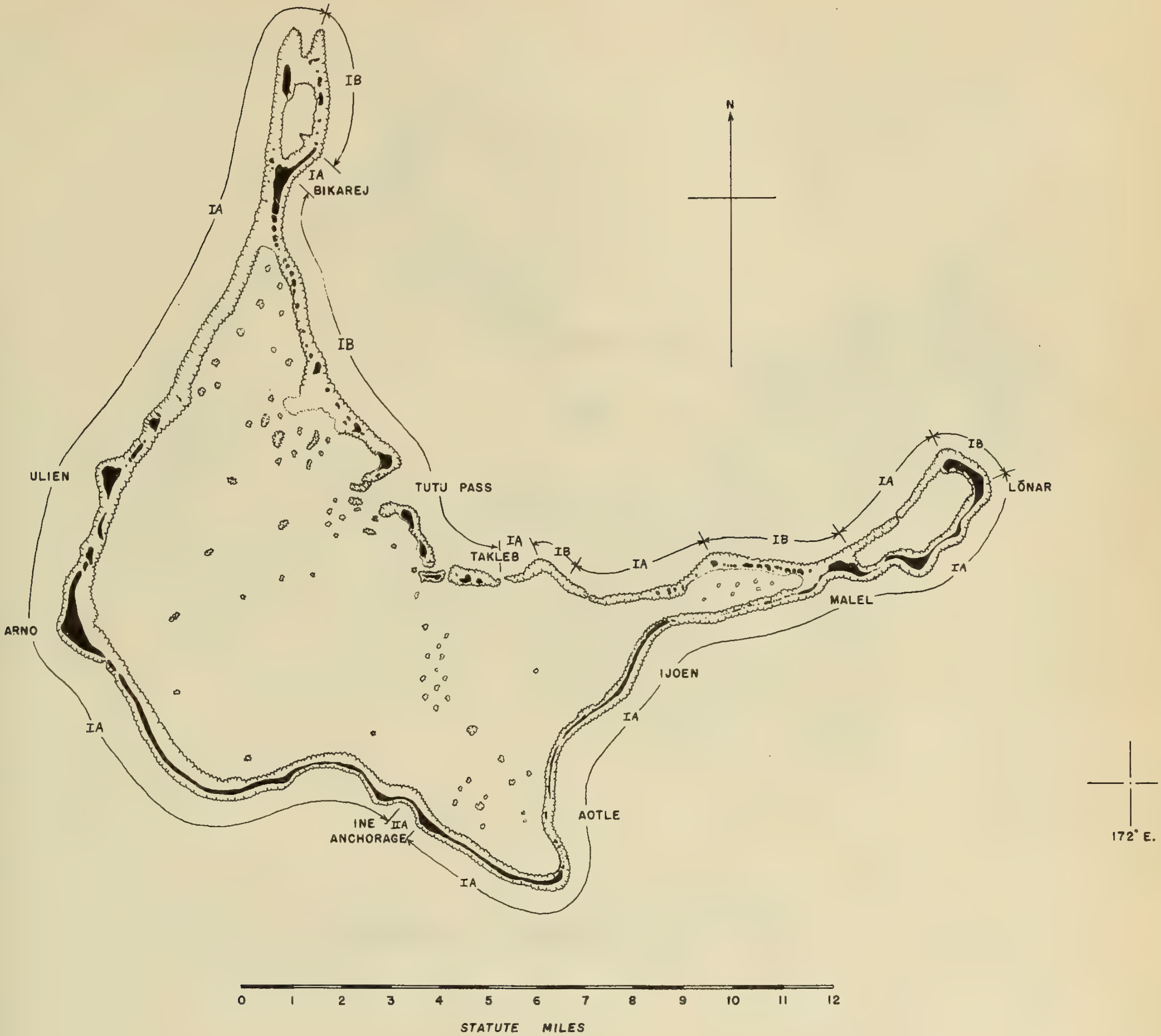


FIGURE I. DISTRIBUTION OF REEF TYPES, ARNO.

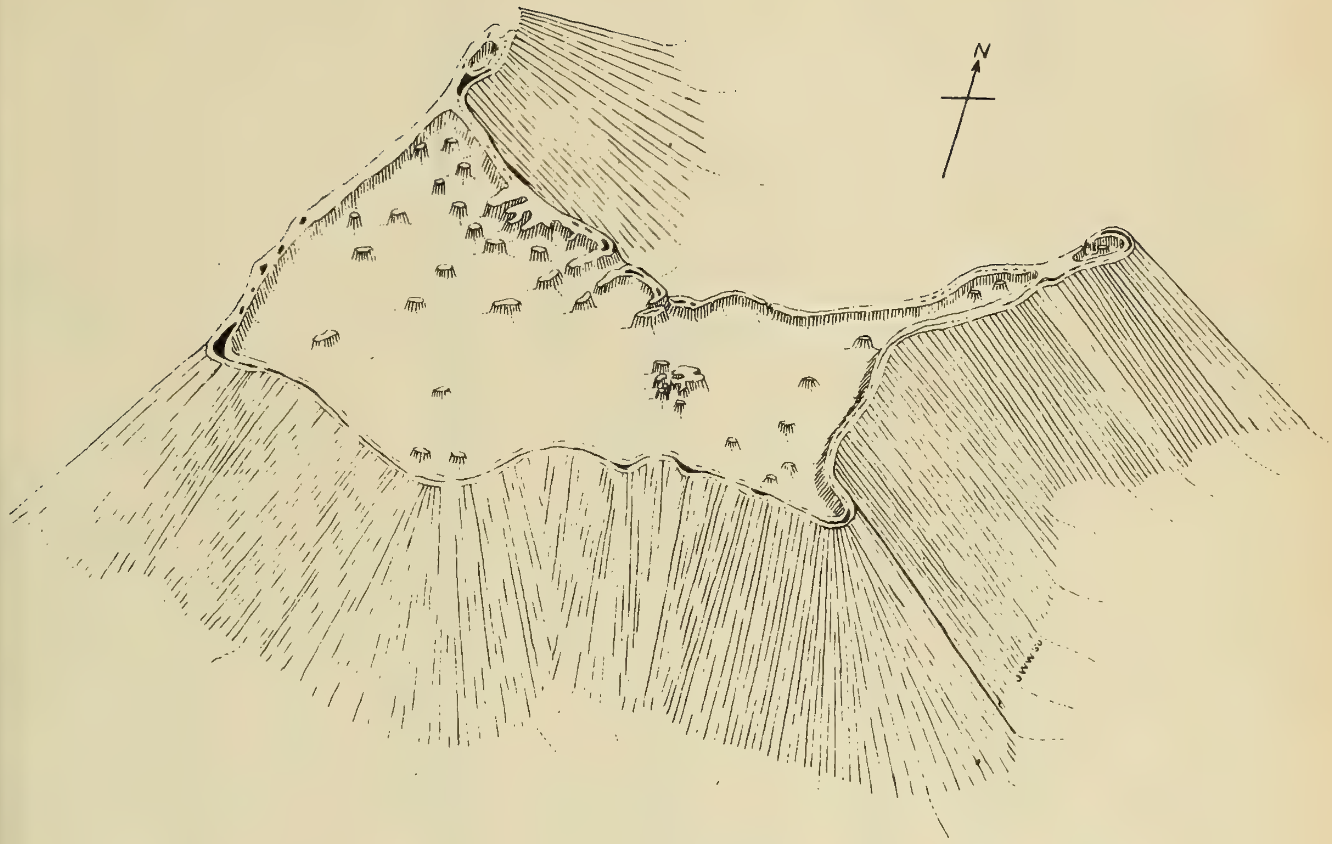


FIGURE 2. PHYSIOGRAPHIC DIAGRAM, ARNO ATOLL.

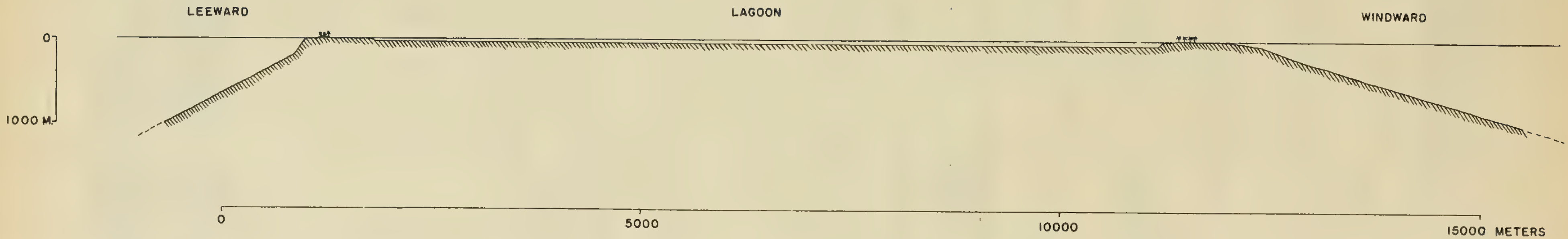
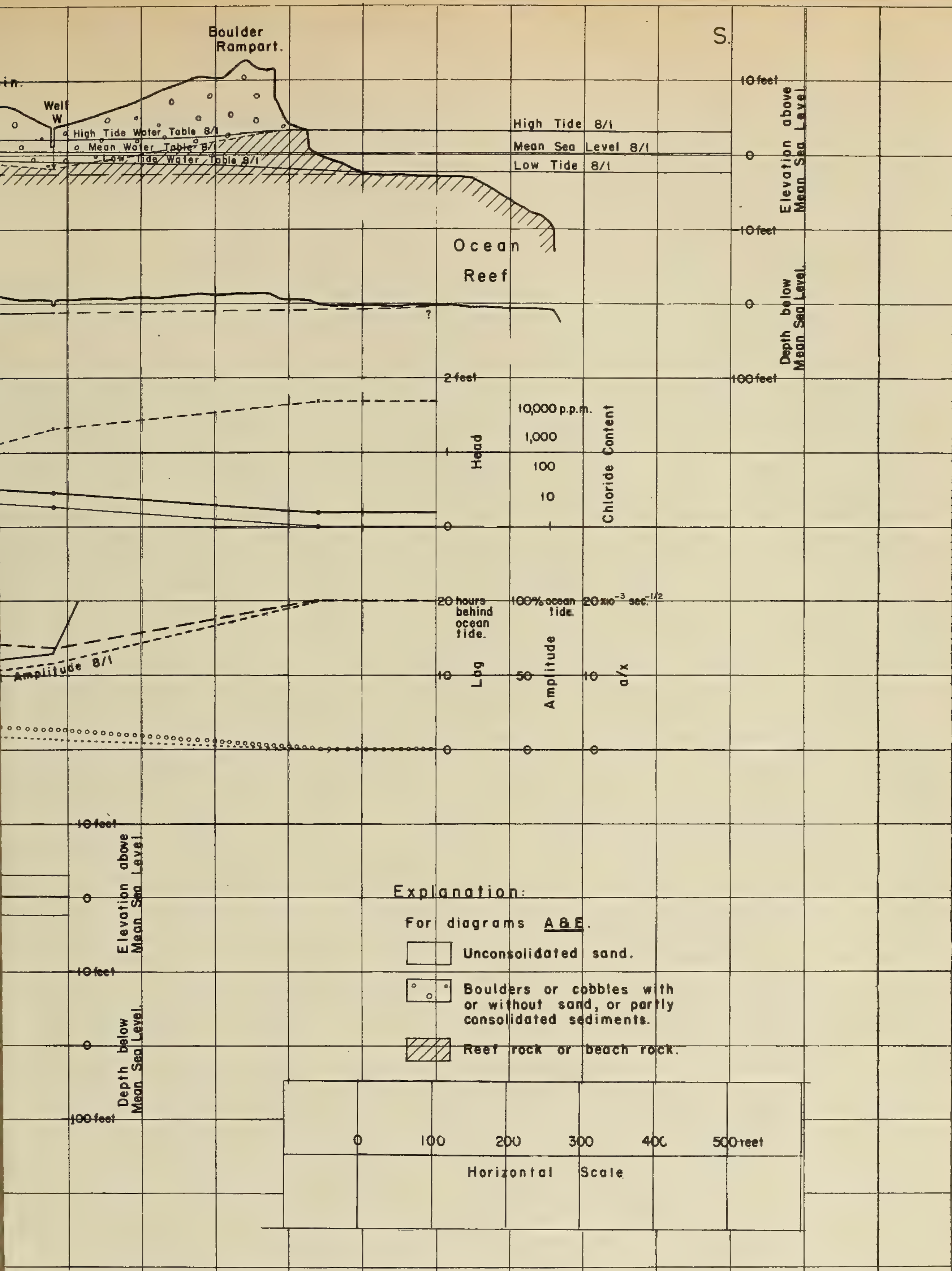
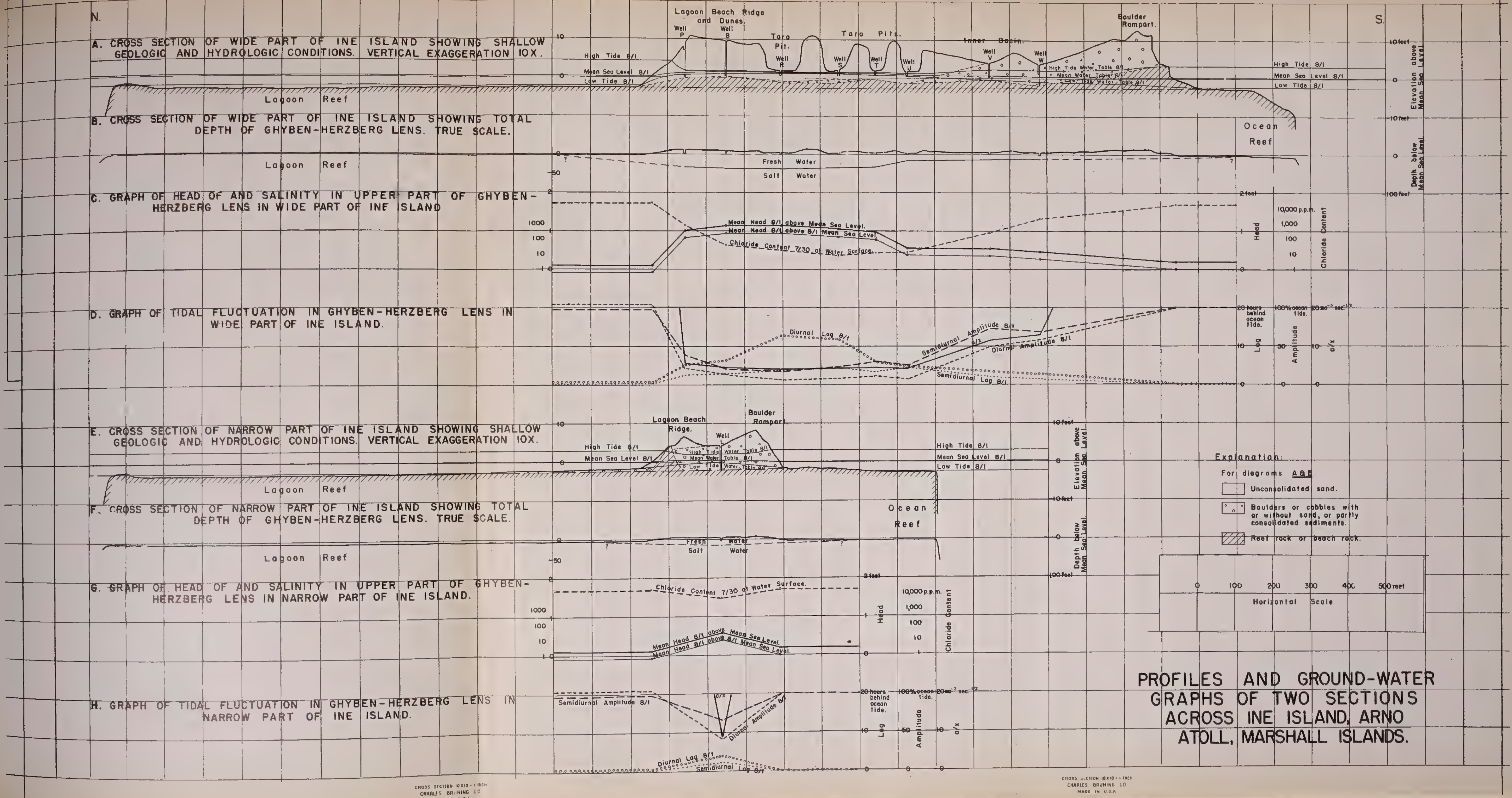


FIGURE 3. TRUE SCALE CROSS SECTION, ARNO ATOLL.



PROFILES AND GROUND-WATER GRAPHS OF TWO SECTIONS ACROSS INE ISLAND, ARNO ATOLL, MARSHALL ISLANDS.



PROFILES AND GROUND-WATER GRAPHS OF TWO SECTIONS ACROSS INE ISLAND, ARNO ATOLL, MARSHALL ISLANDS.

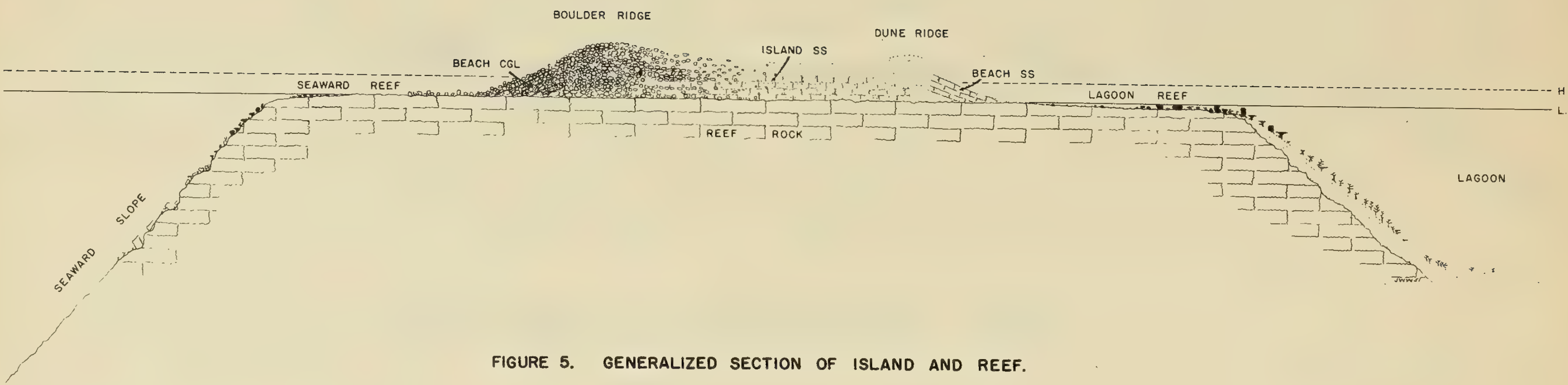


FIGURE 5. GENERALIZED SECTION OF ISLAND AND REEF.

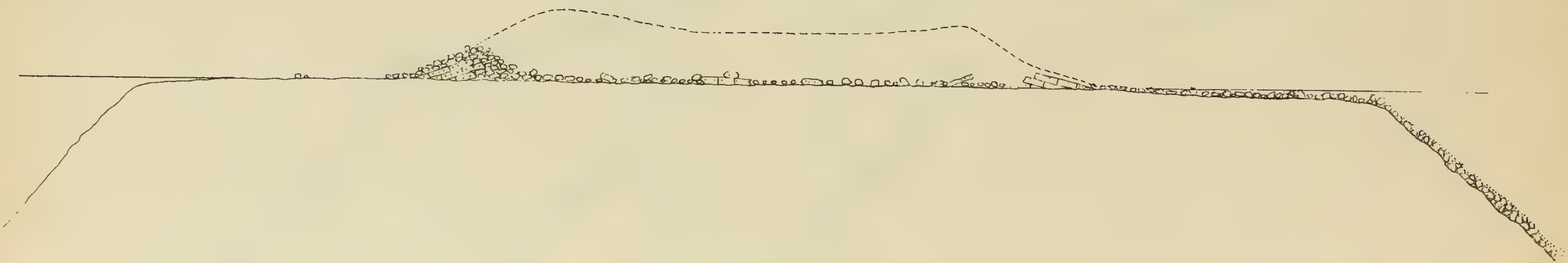


FIGURE 6. SECTION OF ISLAND SWEPT BY TYPHOON.

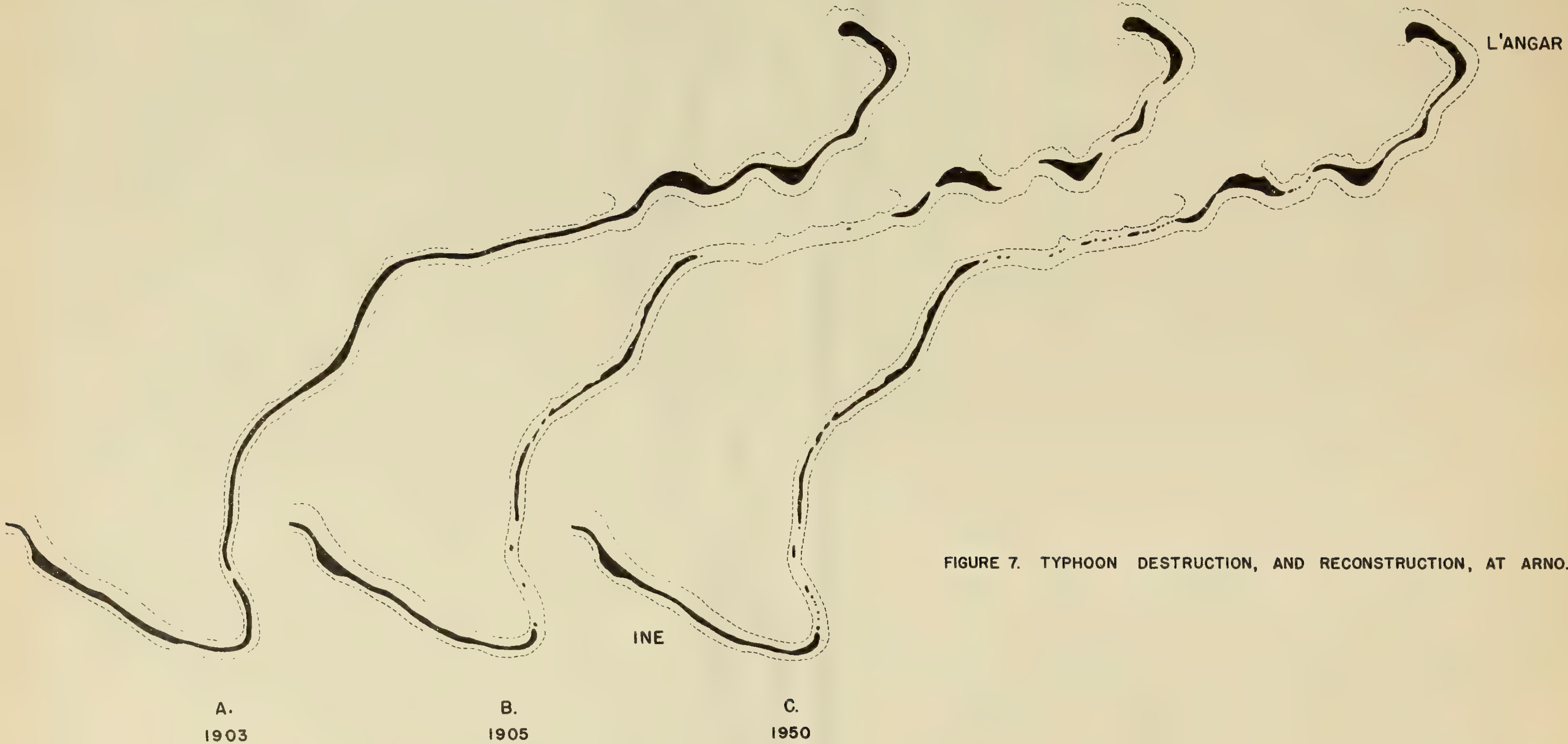
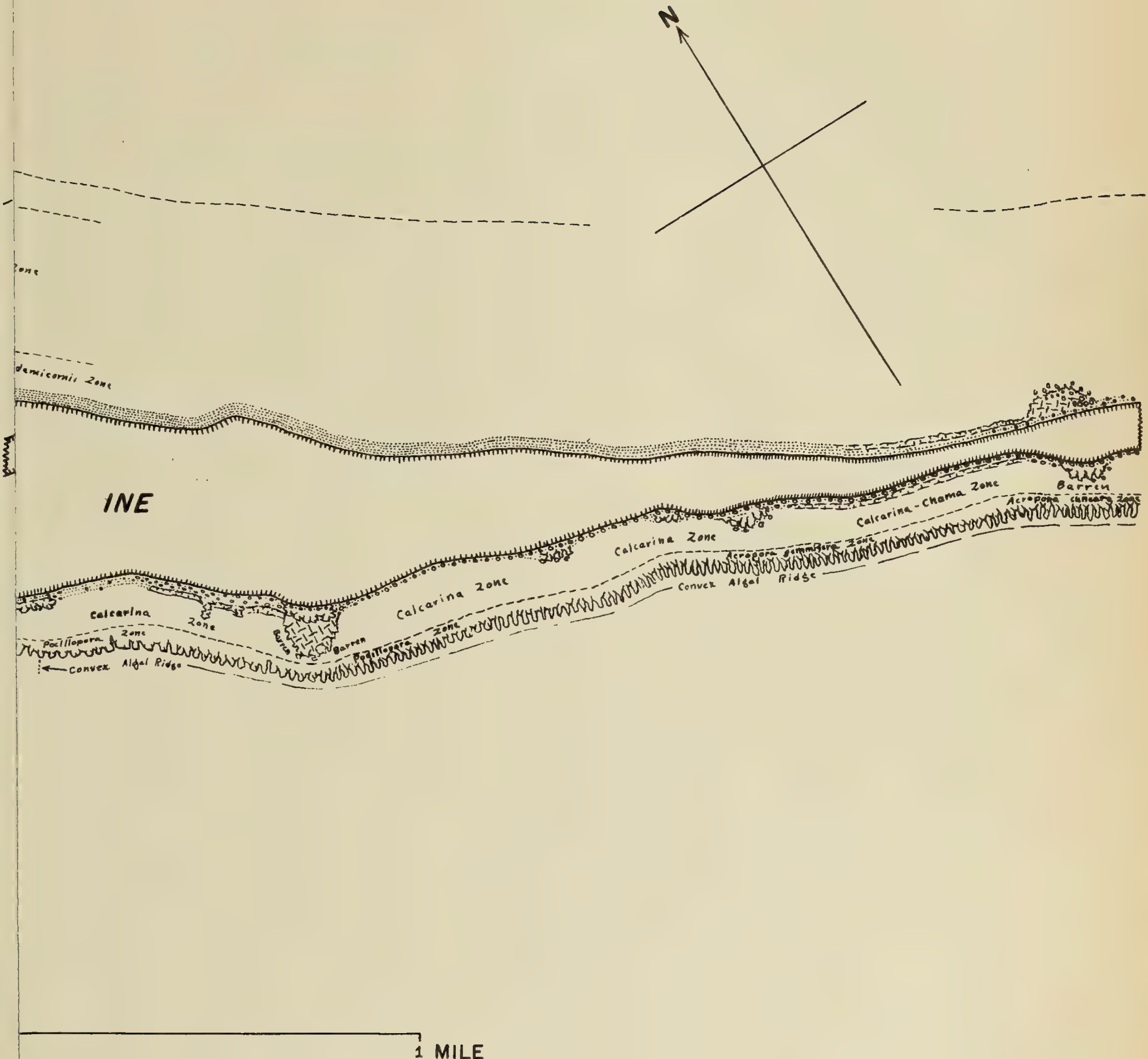


FIGURE 7. TYPHOON DESTRUCTION, AND RECONSTRUCTION, AT ARNO.



N
Zone
demicornis Zone
INE
Calcarina
Zone
Pocillopora Zone
Convex Algal Ridge
Barren
Calcarina Zone
Calcarina Zone
Pocillopora Zone
Convex Algal Ridge
Acropora gemmifera Zone
Calcarina - Chama Zone
Acropora cuneata Zone
Barren
1 MILE

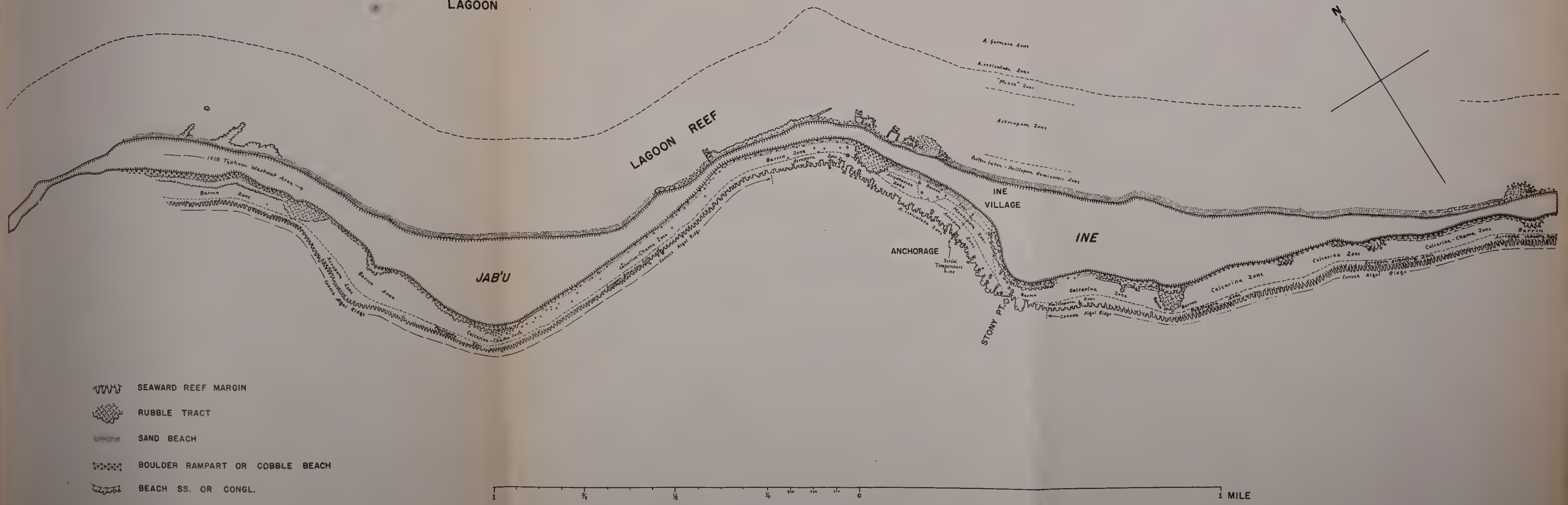


FIGURE 8. DETAIL MAP, PART OF INE I., ARNO. 1:8000.

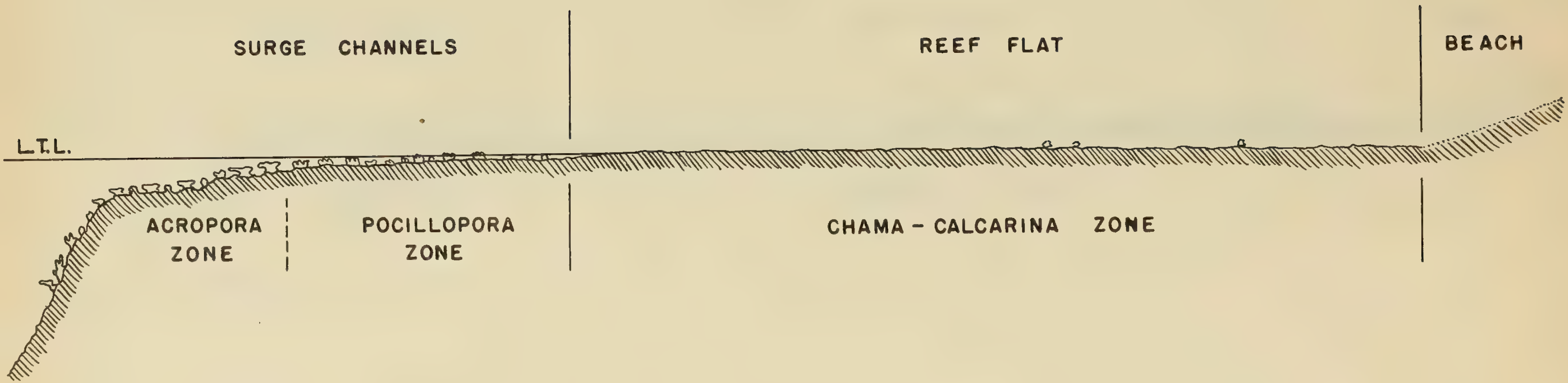


FIGURE 9. SEAWARD REEF, TYPE IA, INE I.

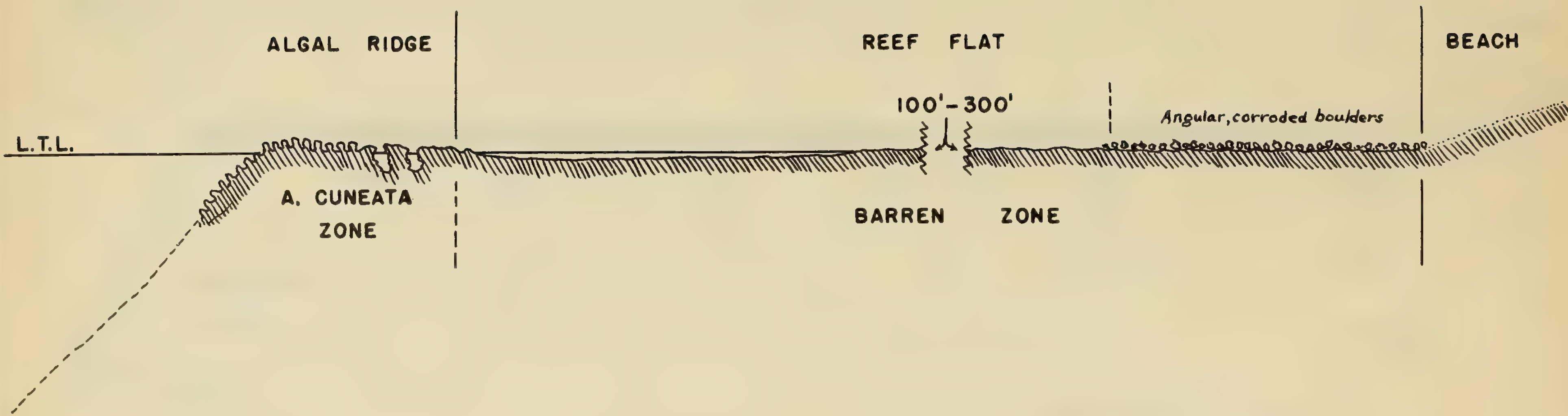


FIGURE 10. SEAWARD REEF, TYPE IB, TAKLEB I.

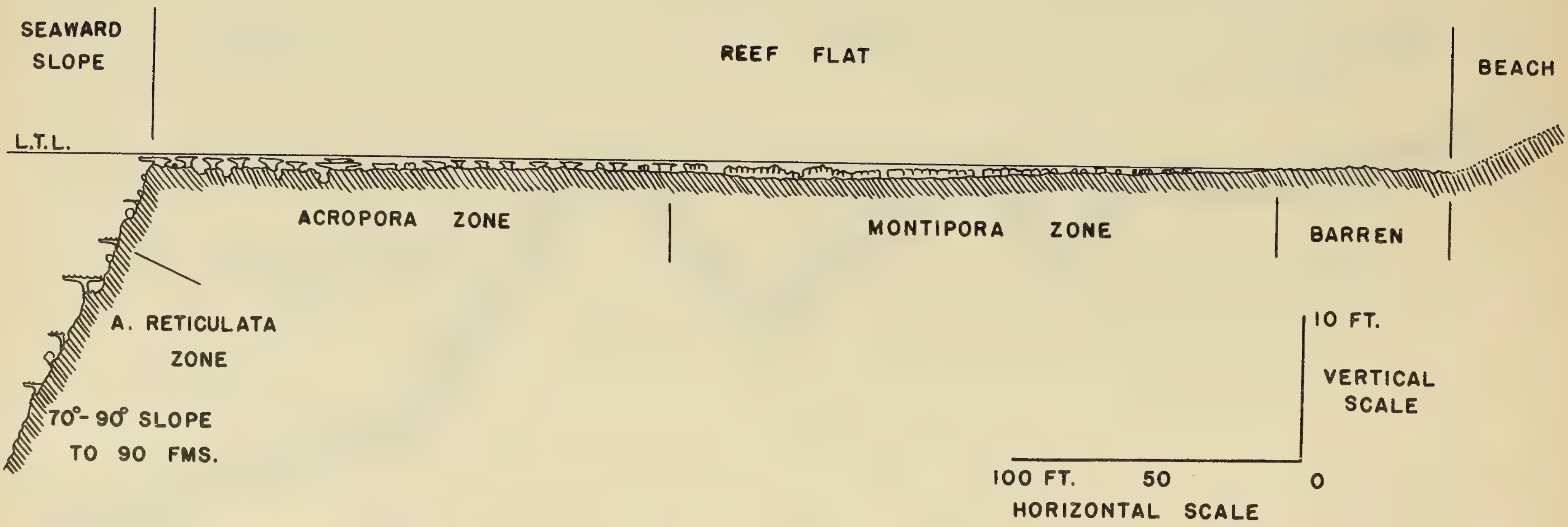


FIGURE 11. SEAWARD REEF, TYPE IIA, INE ANCHORAGE.

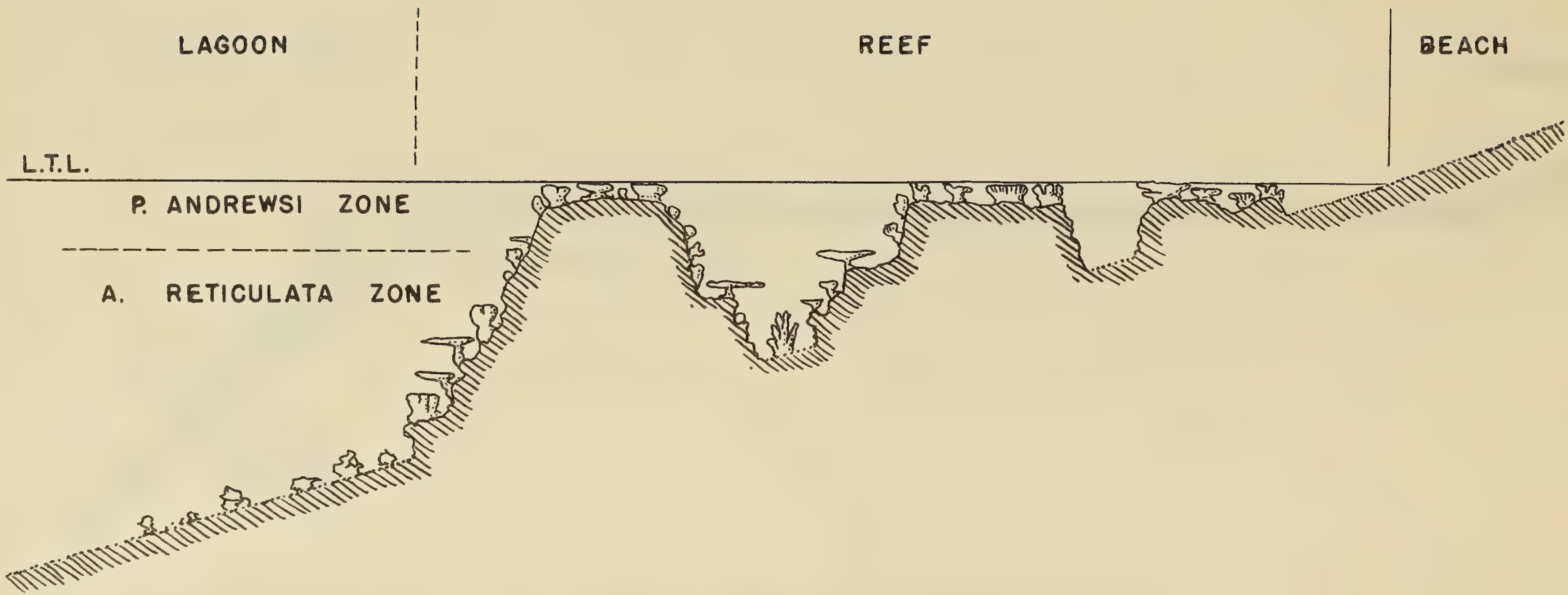


FIGURE 12. LAGOON REEF, LEEWARD TYPE, TAKLEB I.

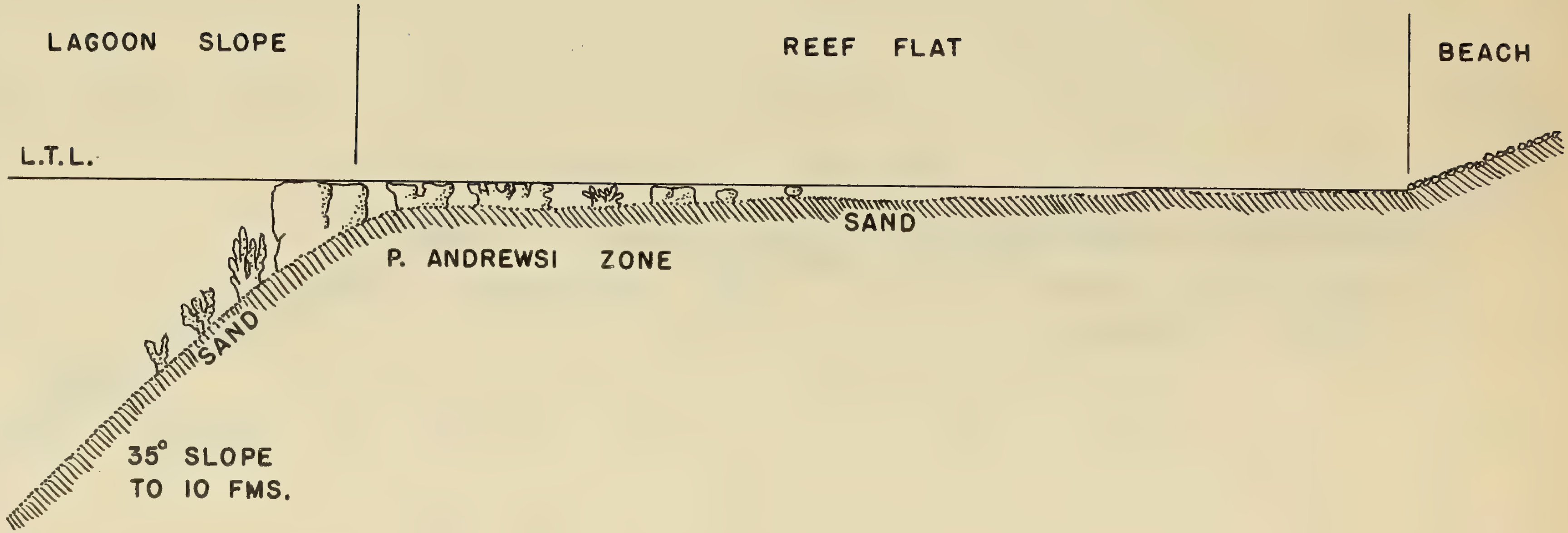


FIGURE 13. LAGOON REEF, ENCLOSED LAGOON, NORTH HORN.

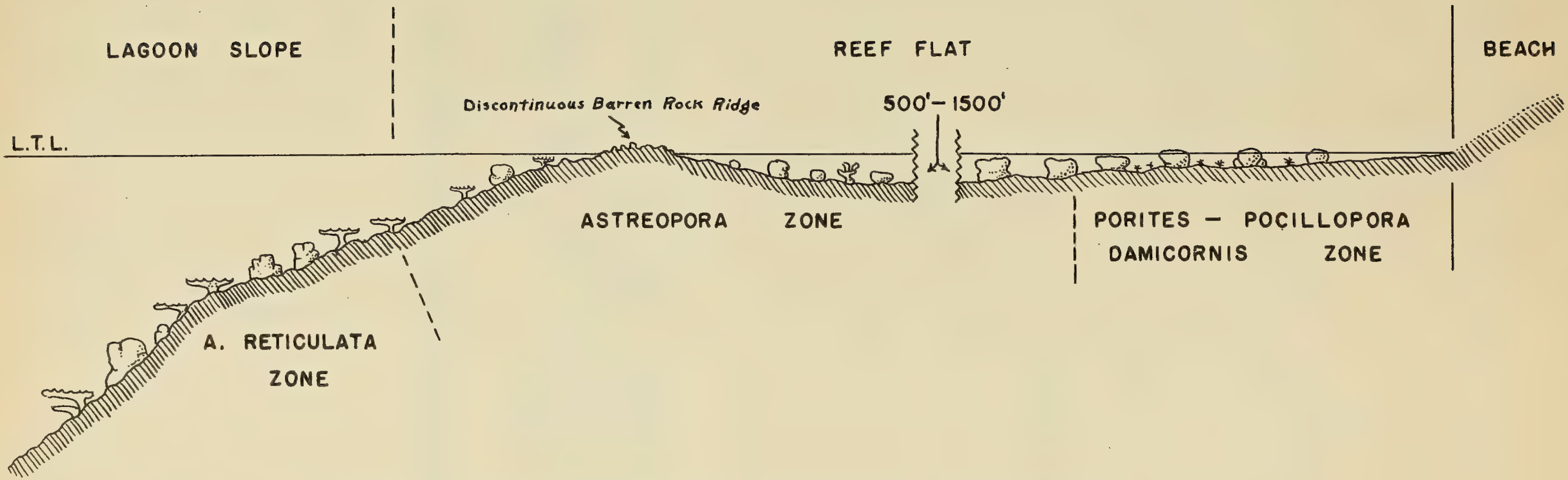


FIGURE 14. LAGOON REEF, WINDWARD TYPE, INE 1.

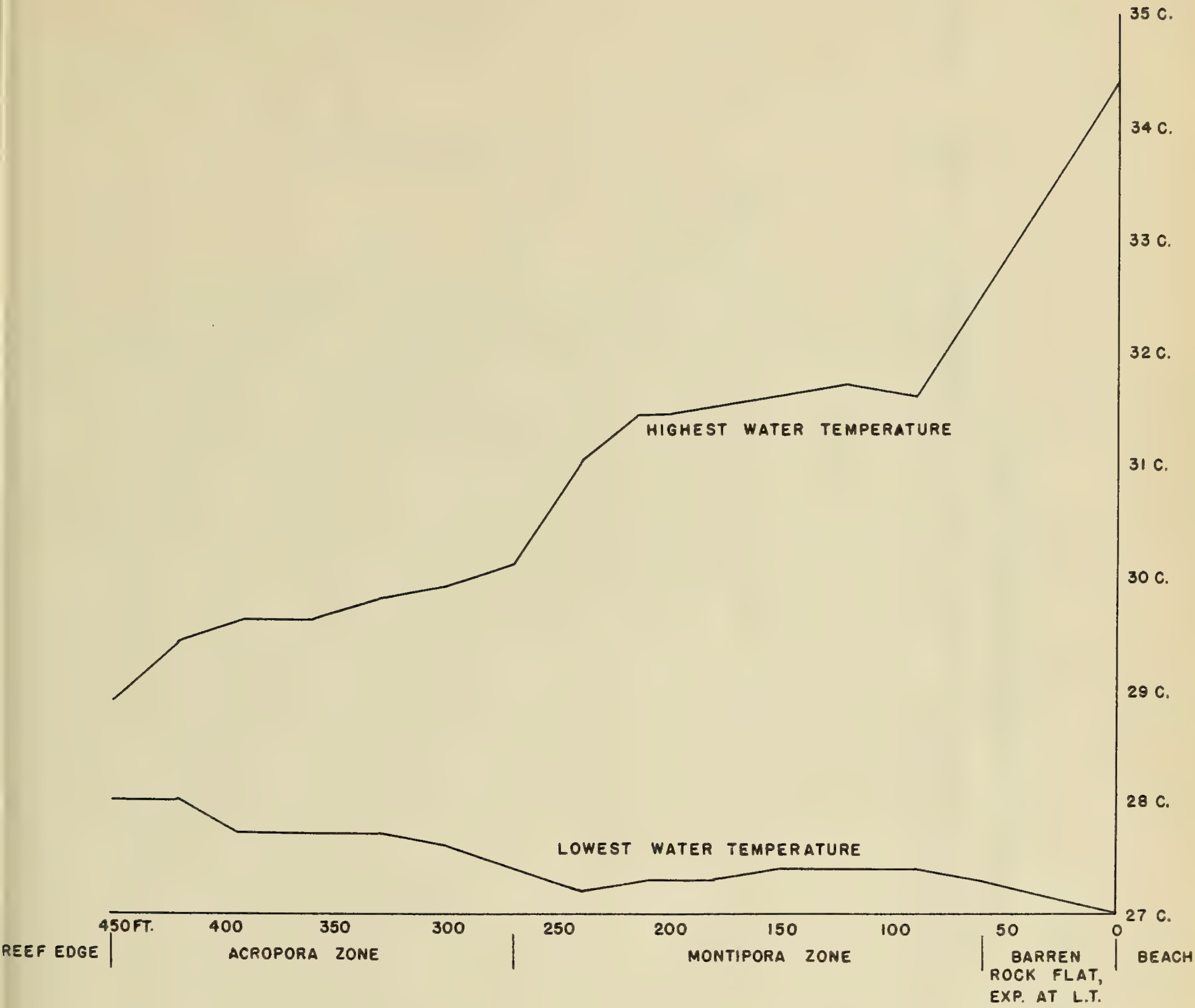


FIGURE 15. WATER TEMPERATURES ACROSS INE ANCHORAGE REEF, JUNE, 1950.

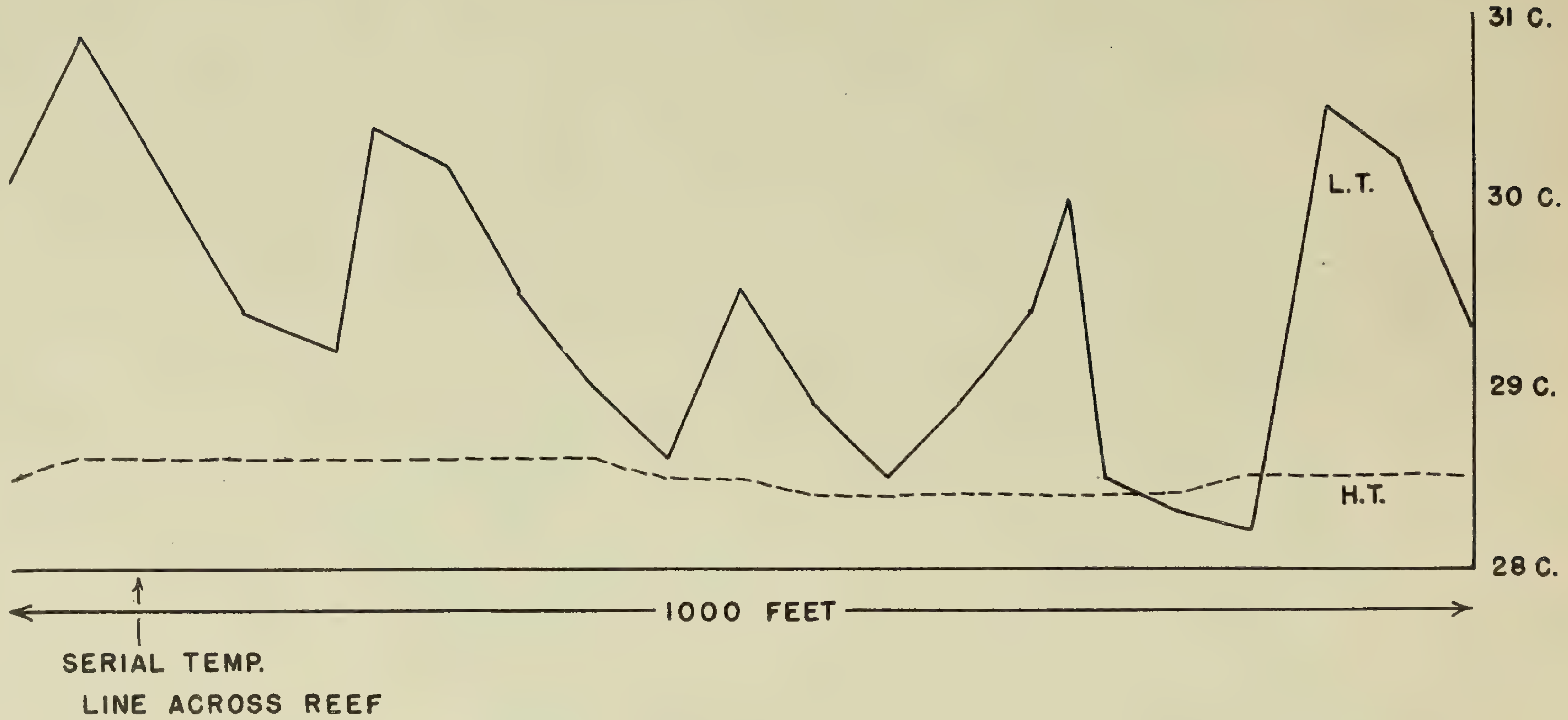


FIGURE 16. WATER TEMPERATURES ALONG INE ANCHORAGE REEF, INNER EDGE OF ACROPORA ZONE.

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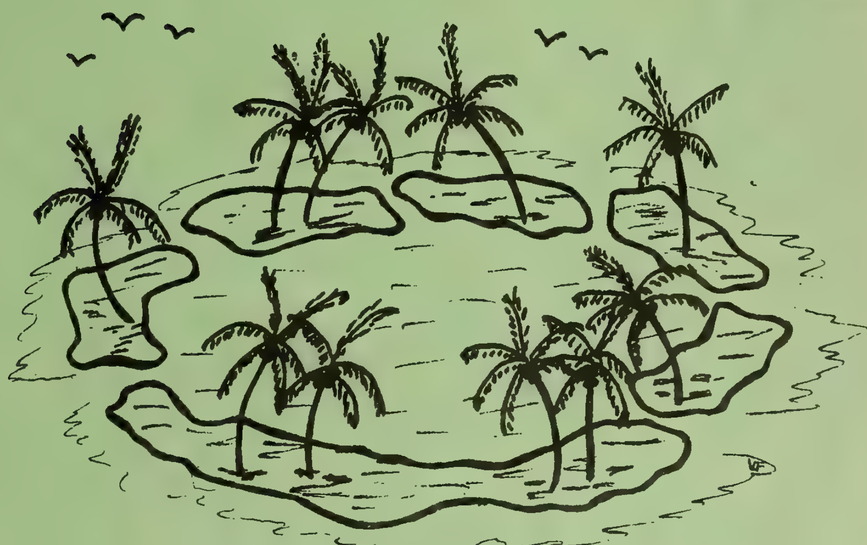
ATOLL RESEARCH BULLETIN

10. *Anthropology-Geography Study of Arno Atoll, Marshall Islands*

by LEONARD MASON

11. *Land Tenure in the Marshall Islands*

by J. E. TOBIN



Issued by

THE PACIFIC SCIENCE BOARD

National Academy of Sciences—National Research Council

Washington, D.C., U.S.A.

ATOLL RESEARCH BULLETIN

Issued by

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ACKNOWLEDGEMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs, CIMA, SIM, and ICCP, during the past five years. The Coral Atoll Program is a part of SIM.

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National Research Council
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ATOLL RESEARCH BULLETIN

No. 10

Anthropology-Geography Study of Arno Atoll, Marshall Islands

by Leonard Mason

Issued by

THE PACIFIC SCIENCE BOARD

National Research Council

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This report covers the field activities of the anthropology-geography section of the Coral Atoll Project at Arno from June 12th to September 13th, 1950. Transportation, living accommodations, and facilities for this work were made possible by a grant from the Office of Naval Research through the Pacific Science Board (National Research Council), and with the generous cooperation of the Office of Island Governments, Department of the Navy, and the Civil Administration staff, Marshalls District, Trust Territory of the Pacific Islands. The University of Hawaii very graciously contributed funds to support the making of a comprehensive photographic record of Arno anthropology and geography.

Within the framework of the Arno Atoll Project, the problems of human relations and of certain cultural adjustments by Arnoese to their physical environment were investigated by the author, with the aid of two assistants, Mr. John Tobin (anthropology) and Mr. Gerald Wade (geography), both graduate students from the University of Hawaii. Tobin and Wade were part of the first contingent of the expedition which departed from Hawaii on June 10, 1950. Due to another commitment, the author was not able to join the group until July 3rd at Majuro. Tobin remained with us at Arno until August 9th, when he left for Majuro to assume his new duties as anthropological adviser to the Civil Administrator, Marshall Islands. Wade and the author were among the last to leave Arno, and returned to Honolulu on September 15, 1950.

One of the reasons why Arno Atoll was selected as the site for the Coral Atoll Project was because of its relative accessibility, as compared with other possible sites in the Trust Territory. In most cases,

team members arrived at Arno within two to five days after departure from Hickam Field, Hawaii. The Navy furnished air transportation from Hawaii to Majuro. Flight time via MATS (Military Air Transport Service) planes from Hickam to Kwajalein is approximately twelve hours, that from Kwajalein to Majuro via the PBM air logistics service is less than two hours. Surface transportation from Majuro to Arno, about eleven miles airline distance from Majuro, required varying periods of time, depending on wind, weather, and type of shipping. Primary dependence was placed by the team on sailing craft, either under contract from Marshallese owner-operators or as a service provided by the Civil Administration school facility at Majuro. Some trips were as short as three hours, the longest was three days.

Daily MATS schedules from Hawaii and weekly logistics flights within the Marshalls, together with almost weekly freighting trips between Arno and Majuro, provided members of the expedition with a fairly regular mail and supply service. With few exceptions, communication with the outside world was most satisfactory, and the success of the project will depend in no small part on this factor.

Land and Water.

The index map of Arno Atoll, which accompanies this report, shows a land area of approximately five square miles, divided into 133 islands of varying size and for which there are 106 Marshallese names. The spelling of these names follows the new orthography which is being worked out in cooperation with Dr. Samuel H. Elbert, University of Hawaii linguist, and the Trust Territory administration. A key to

pronunciation is presented on the map itself. The author proposes that this place-name terminology be used by members of the Coral Atoll Project when submitting their final reports for publication on their respective areas of interest. Copies of this map are being distributed to other members of the project.

Some of the islands are little more than rises of sand above the coral reef, supporting only beach scrub and perhaps a few coconut trees. Other islands, such as Arno or Ine, are several miles long, as much as half a mile wide, and heavily forested in the interior. Although all land in Arno Atoll is owned in accordance with Marshallese custom, just one-third of the islands are permanently occupied by Arnoese. The remaining two-thirds are visited for short periods to harvest coconuts in the production of copra. The main lagoon and the northern and eastern enclosed, smaller lagoons, all of which total approximately 130 square miles of surface area, provide adequate fishing grounds. The lagoons are also utilized as the primary area for communication by outrigger canoes operating between islands within the atoll.

Population.

According to the mid-1950 Civil Administration estimate, Arnoese numbered 1,155. Census samples taken by us during the summer, however, indicate the probability of a somewhat smaller population. The problem of determining accurate totals is rendered difficult by the Marshallese custom of constant migration from one landholding to another in the routine of copra production or for visits to relatives for varying periods of time. A not insignificant movement was also noted between

Arno and the nearby atolls of Majuro and Mili. Limitations of time restricted us to detailed population surveys at only three islands: Arno, Ine, and Jab'ü. When the results of this work are compared with the atoll scribe's official register, discrepancies in the latter reveal that a fairer estimate of Arno's present population might be around 850. The atoll register still includes names of war refugees from other Marshall atolls who were temporarily resident at Arno during 1944 and 1945. Nearly all of these transients were repatriated in 1946 by Military Government, except where ties of friendship, adoption, or marriage bound a few of them more permanently to Arno.

Available statistics on births and deaths at Arno since 1946 indicate a preponderance of births in a ratio of 3 to 1. It appears that this trend will not provoke any serious problem of overpopulation at Arno for many years to come, if we are to accept statements from older Marshallese regarding the more densely populated character of the atoll several generations ago. When the team's analysis of Arno's present food resources, both agricultural and marine, is completed it is certain that additional support for the above statement will be forthcoming.

The Arno people today are scattered in many groups of less than 150 persons each throughout the larger islands of the atoll. The greatest concentrations occur at Ine and at Arno Islands, others of lesser size are at Matol-en, Tutu, Bikarej, Tinak, L'angar, Malel, Kilange, Jab'ü, and Ül-en. The anthropology-geography section of the team visited, for varying periods, the islands of Ine, Matol-en, Jab'ü, Kinajong, Lukwoj, Arno, Tutu, Takleb, Tinak, Kilange, and Malel (one month was spent at Arno Island, one to three weeks each at Ine, Tinak, and Jab'ü).

Natural resources.

Tutu Passage on the northern side of Arno's main lagoon is located at 7° 7' N. latitude and 171° 41' E. longitude. Thus Arno is well within the tropics. Its position in regard to the equator and the tradewind area ensures that the atoll is well supplied with rain throughout the year. Expedition members experienced some difficulty toward the end of the summer in scheduling outdoor work due to an increasing number of rainy days. Although the soil of coral atolls is generally not good, the vegetation picture at Arno is encouraging, especially in the larger islands, where more than enough food plants grow to meet the subsistence needs of the present population. The range of food-producing flora includes coconut, pandanus, breadfruit, bananas, some papaya and limes, arrowroot in great quantities, a little taro-like Cyrtosperma, and small plantings of sweet potatoes. For use in fiber handicraft manufactures, there are adequate reserves of pandanus, hibiscus, coconut, and the beach creeper Triumphetta procumbens.

While the southern Marshalls do not constitute the best stocked fishing area in the archipelago, there appears to be sufficient marine life to support several times the present Arno population. Reef,, lagoon, and deepsea areas at Arno are not utilized by the local inhabitants to the fullest extent possible. The customary land and sea birds of eastern Micronesia are found at Arno, but play no important role in the subsistence economy of Arnoese. Rats and mice, practically the only wild mammalian life, provide somewhat of a pest problem. Insect life includes the annoying mosquito which we found a nuisance in most islands

both night and day. Numerous dogs and cats serve the people more as scavengers than as pets. Pigs and chickens are raised in a haphazard manner as a primary source of meat on festival occasions. Detailed studies of the natural resources of Arno were made by other members of the expedition, and will be reported by them elsewhere.

Effects of the war.

Apart from the general collapse of export-import trade and shipping, Arnoese suffered only minor disturbances during the war. Such was not the experience, for example, of Marshallese at Mili, to the southward, where a large Japanese-garrisoned airbase was bombed continually by American planes in the last year or two of the war; or at nearby Majuro, where the establishment of an important American forward area activity resulted in considerable disruption of another order for Majuro Marshallese. The one outstanding incident of warfare at Arno was the crash of a four-engined American bomber in the lagoon off Jab'ü Island, at which time several of the crew were killed, and others imprisoned by the Japanese. Arnoese buried the crash victims and tended their graves until 1946 when Americans exhumed the remains for more permanent interment in the United States. The plane still rests on the lagoon reef, a tragic reminder of the war, but a source of valuable metal for coconut-grater blades, husking-stick points, and numerous other Arnoese artifacts.

Both Arno and Tutu Islands served as relocation areas from 1944 to 1946 for Marshallese refugees whom American night raiders had spirited away from the by-passed, Japanese-held atolls of Mili, Jaluit, and Maloelab. Some dislocation of Arno community life was occasioned by these temporary residents. Increasing contact with Americans and with

Marshallese from other atolls brought Arnoese out of their previous isolation, and contributed notably to the Western orientation observed today in certain segments of the population.

Arno - a study in contrasts.

At Arno Atoll we had the opportunity to observe a remarkable gradation of population groupings, each of which in a way represented a development in the cultural history of Arno during the past century. Among the islands visited by us, the inhabitants of the eastern horn (known to Arnoese as Baranailingin - "head of the atoll") constitute one extreme in this series. Here, the small communities of L'angar, Tinak, Kilange, and Malel, now nearly two hundred people, have through decades of geographic isolation continued to maintain a profound respect for ancient Marshallese tradition. Greater regard for persons of nobility, stricter observance of tabus in behavioral relationships between certain kinfolk, less concern about exactness of land boundaries, and similar prehistoric emphasis combined to impress us with an atmosphere of antiquity. This primitive provincialism was at once refreshing for its anthropological interest, but at the same time distressing because of the disadvantages met by Baranailingin people in their transactions with more acculturated Arnoese in other parts of the atoll.

The other extreme was observed at Ine village where more than 150 people live in close proximity, in Japanese-style houses antedating the war and in Marshallese constructions remodeled with boards, plywood, and corrugated iron sheeting scrounged from American military bases at

Majuro and Kwajalein Atolls. In its shanty-town aspect, Ine recalls the impoverishment of slum sections in many of our larger cities. The diet of Ine inhabitants includes more of rice and tinned meats than is the case elsewhere in Arno. Ine is the political and economic center of the atoll, as well as the primary port for small boats operating between Arno and Majuro. Even the mission is established at Ine, thus making that village the spiritual focus of the predominantly Protestant population of Arno. It was natural enough that Ine served us as expedition headquarters from which sporadic survey trips were undertaken to the outer islands for sampling purposes.

Arno Island, the richest in natural resources and supporting the largest population of all islands in the atoll, assumes an intermediate position with respect to the cultural extremes noted at Baranailingin and Ine. Arno inhabitants depend more upon local foods than do those at Ine, and build their houses more often of thatch and local timbers. One observes at Arno a fair degree of cultural awareness of the West -- not as prominently as at Ine, but quite different from the relative lack of sophistication in the eastern horn. As a result of decades of contact with traders and missionaries, who divided their labors between Arno and Ine, the social life of Arno Islanders is interwoven with that of Ineans. However, cultural equilibrium at Arno Island is well maintained, and appears likely to continue in that manner for years to come. Not so at Ine, where the population as a whole seems committed to a new life oriented toward the West.

As the above situation is viewed in its atoll-wide aspect, with special reference to economic and political affairs, these cultural differences combine with personalities to present a confusing organizational scheme replete with conflict and intrigue.* Since 1944, American administration contacts with Arnoese have been concerned with ramifications of this conflict. We devoted much of our time to an analysis of the situation, realizing that as long as it persists a more complete utilization of atoll resources and manpower cannot be attained. We trust that our observations will be of assistance to Civil Administration officials in their future relations with the Arno people.

Communication between Arnoese and Americans.

The presence during the summer of twelve American scientists at Arno afforded the islanders considerable diversion from their usual routine. At one time or another most of the villages were visited by small parties from our headquarters at Ine. Quite obvious on these occasions was a general lack of understanding of American custom by Arnoese, for they eagerly sought opportunities to learn from us more about America and Americans. We communicated with the people almost entirely through Marshallese interpreters, although one or two members of the expedition acquired sufficient facility before the summer's end to converse in limited manner in the vernacular. Only eight or ten Arno residents understood English well enough to speak with us easily. We hired one local man as regular interpreter, while two others

* A more detailed description of the economic, political, and land administration of this situation is presented in subsequent sections of this report.

(school teachers from Ine and Arno Islands) were taken on for short periods when their teaching duties permitted. Majuro provided two additional fulltime interpreters for the first part of the season. All interpreter personnel was under the supervision of James Milne, a Marshallese and official interpreter loaned to us by Kwajalein Navy officials. Without Milne's assistance the anthropology-geography work of the expedition could not have been accomplished in the three months available.

Ordinarily, Arnoese have almost no contact with Americans in their own atoll. Official field trips visit Arno (either Tutu or Ine Islands) only four times each year, for a period of several hours on each occasion. Field trip parties normally include representatives from the Political Affairs, Medical, and Education Departments, and from the Island Trading Company. Time ashore is too limited for adequate discussion of problem areas. The inability of the people to speak English and a comparable lack of Marshallese facility by American officials (recently, there are one or two important exceptions) requires that practically all contacts be effected through interpreters. Some difficulties in the conflict situation noted in the previous section of this report have emanated from the fact that certain official interpreters at Majuro are Marshallese from Arno, or otherwise prejudiced in favor of one Arno group or another, and fail to be impartial and objective in their interpretation of the situation to American officials.

The short distance to Majuro and the small boats now available for

trips from Arno have provided certain Arnoese with greater opportunity to present their own problems at Majuro where, with more time and with their own interpreters, more satisfactory communication with Civil Administration is achieved. Even the latter course, however, does not necessarily provide a fair presentation of the Arno situation. It must be obvious that before more adequate comprehension of the Arno conflict can be attained, American officials must learn more and better Marshallese or else exercise greater caution when depending upon Marshallese interpreters. Furthermore, the complexity of the Arno conflict is such that it cannot be understood by any one in the course of four short field trips each year or through casual conversations with Arnoese visitors at Majuro.

Commercial enterprise.

From 1944 to 1947, Arnoese produced large quantities of fiber handicraft (fans, doilies, mats, belts, cigarette cases, and cup coasters) for sale to traders of the U. S. Commercial Company (USCC), the predecessor of Island Trading Company (ITC). Later, as shipping improved and copra production was revived, handicraft declined in favor of copra as the primary source of money income for Arnoese. Present income from handicraft is almost nil, due to an ITC policy whereby handicraft purchases are being restricted until surpluses of USCC stock are moved. In the year beginning July 1, 1949, Island Trading Company at Majuro, the only buyer of Arno copra, purchased approximately $40,000 worth of copra from Arno producers, averaging about $50 per capita. We collected considerable data on copra production by the month, by district, and by shipment to Majuro, and on distribution of copra income

among the Arno population according to a complex social stratification and land ownership system. A more detailed analysis of this material will be forthcoming in the near future.

Retail stores are maintained at Ine, Arno, Tutu, and Malel Islands. Storekeepers acquire their goods through the Arno Wholesale Company at a retailer's discount which enables them to make some profit on sales to the Arno consumer. The Arno Wholesale Company is an organization built on a capital investment by twelve Arno Marshallese, who control all trade imports to Arno (with the recent exception of mail order purchases from U. S. mainland firms on direct order from Arno consumers). The Arno company buys its supplies at wholesale prices from ITC Majuro. Until recently, prices at wholesale, retail, and consumer levels were controlled by Civil Administration order, but now only certain commodities remain in this restricted category. In practice, the Arno Wholesale Company continues to dictate retailer and consumer prices to some extent at Arno. Storekeepers sometimes act as copra brokers, buying from the Arno producer and shipping at their own expense to Majuro for resale there at a better price. Many Arno producers, however, prefer to deal directly with ITC Majuro because of alleged malpractice in weighing and grading by certain Arno storekeepers. This involves shipping at the producer's expense, but appears to be profitable in view of the number who continue to follow this course.

Since outrigger canoes are not suitable for shipping heavy cargo between Arno and Majuro, some groups and individuals at Arno have built or acquired larger boats for this purpose. In July, 1950, the Atoll

Council purchased a newly converted ketch from the administration-sponsored boatworks at Kwajalein. With such sailing craft, ranging from 28 to 50 feet in length and carrying from three to 16 tons, copra and trade goods are being freighted on fairly regular and frequent schedules to provide Arno boat owners and operators with an additional source of money income. It is important to note that Arnoese are now completely independent of Navy shipping in their trading requirements, and maintain all necessary contacts with Majuro by using Arno sailboats, or craft from other atolls for which contracts are made on a trip basis. This situation should improve so long as Majuro remains the center of ITC activities, for Arno is most fortunately located of all Marshall atolls in respect to its position near Majuro. Should the trading center be removed to Jaluit or to Kwajalein, as has been rumored in the islands, the Arno people would fall into a very sorry state of affairs from an economic viewpoint. Their copra output would undoubtedly slump if larger craft were not available to make the longer hauls worthwhile.

Political authority.

The government of Arno is a function of the Atoll Council, an American innovation since the war and composed of the headmen of more than 100 extended families. The atoll officials are theoretically elected by popular vote, even secret ballot -- Magistrate, Scribe, and Judge. Traditionally, Arno is divided into four areas, roughly north, east, south, and west (Jabonwör, Rearlab-lab, Ajeltokrök, and Keb-jeltok respectively; or more popularly referred to by Americans as Tutu, Malel,

Ine, and Arno). For each of these four areas the Council appoints a Village Headman, a Policeman, and a School teacher, all on salary and paid from atoll funds. The atoll budget, providing primarily for the salaries of fourteen officials (the Judge receives no salary), is met by taxes levied on male adults to the extent of $13 per annum, by licenses derived from stores and bakeries, and from fines assessed by the Village Headmen or the Atoll Court. (Schoolteachers are selected and trained by the Civil Administration Education Department, and installed in their positions with the approval of atoll officials. An additional category of "official" is the Health Aid, of which there are three (Arno, Ine, and Malel), selected and trained by the Civil Administration Medical Department, but paid by the Administration from non-atoll funds.)

The preceding paragraph describes Arno council government as conceived in theory. In practice, it fails to conform even to minimum standards of American democracy. This is not only the fault of improper indoctrination of Arnoese by Civil Administration officials who instituted the system, but stems also from a basic conflict between the concept of council government and the traditional hierarchy of Marshallese authority which still flourishes in most of Arno. The conduct of an election held just before our arrival was described in such terms that strong doubt exists as to the extent of popular support for any "elected" official at Arno. Indeed, the Arno Council is dominated by the same group of individuals that organized the Arno Wholesale Company, which controls nearly all of Arno's import trade. Since the Village

Headmen, as appointed by this minority group in the name of the Council, are probably the most active of Arno officials, a situation pregnant with dissension has been created whereby "villagers" are supervised by leaders not always of their own choosing. It was our observation that council meetings were not properly announced in advance (consequently, were not well attended nor representative). Schoolteachers have not been paid for many months because the system of tax collection as set up by the council does not function properly. Many Arnoese refuse to pay their taxes until a more representative and efficient type of local government is established.

Land.

The real source of the conflict at Arno is land and the privileges of its use and ownership. According to Marshallese custom, all land on an atoll is owned by royalty (iroij). It is administered by an older man or woman of the royal lineage, which position (iroij lab-lab, or paramount chief) is inherited from the mother's side of the family. In some atolls, there may be only one royal lineage in control, as was the case at Arno in the late nineteenth century. In other atolls, two or more lineages may hold the area in separate and independent portions, which is the case today at Arno as the result of a family quarrel 60 or 70 years ago. In any case, the land is always divided into small landholdings, each of which is occupied or worked by commoners (kajur) under the direct supervision of a headman, the alab. Between the alab(s) and their iroij lab-lab there is usually (although not always) an intermediate supervisor, who may be of the royalty himself (iroij erik, or little chief), or of common birth but raised to privileged status

(läatök-tök) because of his or his ancestor's abilities. The position of each person in the hierarchy is hereditary in relation to the land, except when the paramount chief wishes to effect a change at his own pleasure or under pressure from his advisers. Thus, the royalty own the land and receive tribute from the commoners who occupy it and work it for them. The intermediaries receive their share of the tribute as it passes up the line, in proportion to the relative importance of their positions. The paramount chief once was responsible for the welfare and safety of the people on his lands, a reciprocal feature which must have been a strong supporting factor, but which appears now to be more prominent in its oversight.

The conflict at Arno is not recent in origin. It began just before the turn of the century when the paramount chief attempted to take the wife of his maternal cousin, initiating a quarrel which split the lineage and the entire atoll wide apart. By 1904, the German administration in the Marshalls had put an end to warfare between the two groups, but they failed to stop the political maneuvering which followed. When the Japanese replaced the Germans in 1914, the Arno trouble flared up anew. Tales of lobbying and bribery by both parties at Jaluit, the Japanese capital in the islands, provide a lurid background for charges of illegal transfers of land at Arno in the decade or two that followed.

When the Americans came to Arno in 1944, they discovered the two groups, still independent and hostile to each other. One of them was ruled by Töbö, last of the senior branch of the old lineage and himself

an autocrat in the Marshallese tradition. The other group had lost its leader, a woman named Liwaito, during the thirties and as yet no successor had been agreed upon by her five iroij erik. Dissension began among Liwaito's group as three of the iroij erik attempted to break away completely and become independent. A fourth iroij erik was being supported by the fifth as iroij lab-lab to succeed Liwaito. In 1947, "incidents" at Arno became so frequent that the Civil Administrator at Majuro investigated the entire situation. He was hampered by the necessity of working from Majuro and of depending upon interpreters who were not impartial in the matter. His solution, admittedly an expedient, recognized the independence of Töbö, and of each of the five iroij erik of Liwaito except as any one of them should agree to support any other as Liwaito's successor. Since that time, the iroij erik of Liwaito have in effect become iroij lab-lab of the stature of Töbö, three of them siding with him in an attempt to oust the other two from their lands. This coalition on Töbö's side has very nearly the same membership as the Arno Wholesale Company, and as the minority group which controls the Atoll Council.

Conflict at Arno is not by any means limited to the upper brackets. In the course of our investigation of land ownership, tenure, and inheritance rights, we encountered innumerable disputes between commoners over the same landholding, between an alab and his iroij erik, and so forth. About twenty-five cases of disputed land rights were recorded by us and investigated as to claims of the disputing parties, background for their claims, opinions of other Marshallese about the dispute,

action taken on the case to date, and present status of the disputed land. We tried insofar as possible to avoid giving Arnoese the impression that we were able to make any decision in these matters. We constantly emphasized that we had no official status, and referred all requests for settlement to the Civil Administration at Majuro.

The people of Arno constantly reminded us that increased copra production and rehabilitation of lands neglected during the war could be achieved much quicker if the Administration would settle disputes which exist in regard to nearly every landholding in the atoll. Using a hand compass and pacing off distances, we made large-scale land maps of Arno, Ine, Tinak, Jab'ü, and Kinäjong Islands. These were compiled in consultation with occupants of the landholdings and with officials of both island and atoll for accuracy, and include information about the rights of workers, alab, iroij erik, and iroij lab-lab on each landholding, as well as notes about crop production, housing, and other cultural facilities. We checked our results with cadastrals previously prepared by Civil Administration, but found them to be in error so often that we were forced to discard them for any kind of checking of our own work. The administration maps apparently had been drawn up by Marshallese interpreters with little or no American supervision, and contained errors not only of carelessness but also of intentional misrepresentation of land rights in disputed areas. Certainly there is no peace of mind at Arno today whenever the subject of land arises.

Viewing the Arno conflict in its broad outlines, the author suggests the following problem areas for further consideration and investigation

by Civil Administration at Majuro:

(1) the very basic differences of opinion which exist between the Töbö and Liwaito groups, extending from the chiefs themselves down to the commoners on the land;

(2) the fervent desire of one of Liwaito's iroij erik (Lujim) to support another of them (Jiwirak) in the position of iroij lab-lab, as well as the similar expression of loyalty to Jiwirak as voiced by some commoners under the three other iroij erik;

(3) the revolt of the three iroij erik (Felix, Abijai, and Lainlij) from the Liwaito group, their future status, and their relations with commoners on lands under their control;

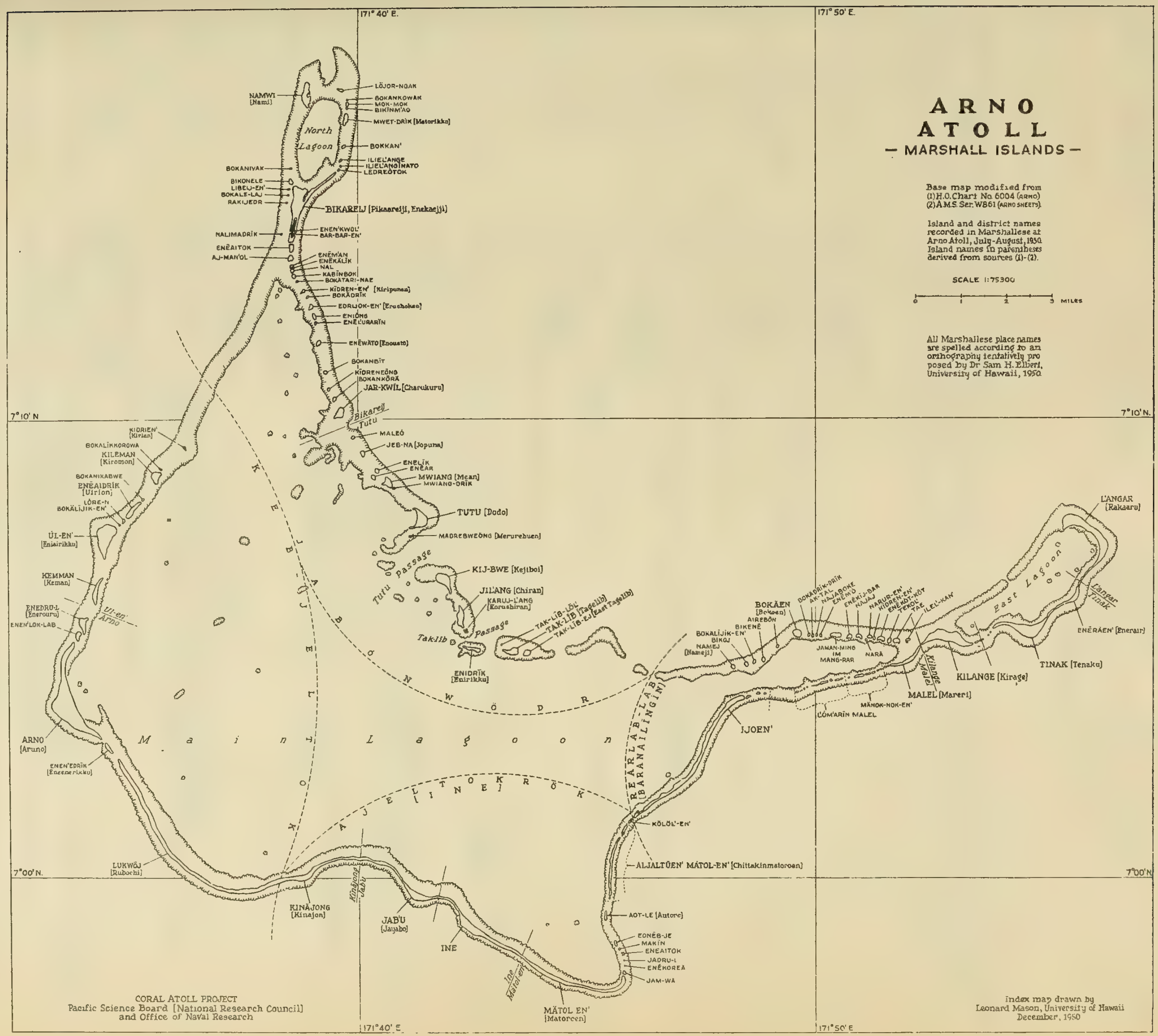
(4) a strengthening of the Atoll Council, and its possibilities as a court for mediation of land disputes; and

(5) the relation of Civil Administration to the Arno people, channels of communication, degree and method of supervision of council activities and land disputes.

It was the author's good fortune to find time at Majuro upon his return from Arno when he could talk at some length about these problem areas with the Civil Administrator, Cdr. R. W. Kenney, USNR. At the time, the author made some tentative suggestions for amelioration of certain aspects of the Arno conflict, but his own observations could not be exhaustive without a more careful analysis of his field notes. The author hopes to be able to answer more of Commander Kenney's questions of fact in the near future as he completes this work.

Miscellaneous.

Additional information in considerable detail was secured about the preparation of many Marshallese foods in season during our stay at Arno, and about the processing of the following fibers for handicraft production: coconut, pandanus, hibiscus, Triumphetta procumbens, and mangrove. About 950 black-and-white photographs were made of various activities, about 800 Kodachrome slides (35 mm.) of similar content were made, and over 5,000 feet of 16 mm. Kodachrome movie film of food preparation, dances, handicraft manufactures, outrigger canoe handling, and other Arno activities were exposed, from which a documentary movie is being prepared about Arno community life.


ARNO
ATOLL
— MARSHALL ISLANDS —
Base map modified from
(1) H.O. Chart No 6004 (ARNO)
(2) A.M.S. Ser. W861 (ARNO SHEETS)
Island and district names recorded in Marshallese at Arno Atoll, July-August, 1950. Island names in parentheses derived from sources (1)-(2).
SCALE 1:75300
0 1 2 3 MILES
All Marshallese place names are spelled according to an orthography tentatively proposed by Dr Sam H. Elbert, University of Hawaii, 1950.
North Lagoon
Main Lagoon
East Lagoon
KEJBAJEL
WÖDR
AJELTINEJ KRÖK
REARLAB-LAB [BARANAILINGIN]
NAMWI [Namil]
BIKAREIJ [Pikaareiji, Enekaejji]
TUTU [Dodo]
KIJ-BWE [Kejibol]
JILANG [Chiran]
ENIDRIK [Enirikku]
BOKAEN [Bokoen]
IJOEN'
KILANGE [Kirage]
MALEL [Mareri]
TINAK [Tenaku]
L'ANGAR [Rakaaru]
ENERAEN' [Enerair]
ALJALTÜEN' MÄTOL-EN' [Chittakinmatoroen]
MÄTOL EN' [Matoroen]
JAB'U [Jayabo]
INE
KINAJONG [Kinajon]
LUKWÖJ [Rubochi]
ARNO [Aruno]
KEMMAN [Keman]
ÜL-EN' [Eniairikku]
KILEMAN [Kiromon]
Tutu Passage
Takilb Passage
171° 40' E.
171° 50' E.
7° 10' N.
7° 00' N.
CORAL ATOLL PROJECT
Pacific Science Board [National Research Council]
and Office of Naval Research
Index map drawn by
Leonard Mason, University of Hawaii
December, 1950

F-2642

MARSHALLESE PHONEMES AND ORTHOGRAPHY
(A tentative proposal)

VOWELS		CONSONANTS	
Front unrounded	i, ï, ë, e, ä	Stops	b, b', bw, t, k, kw
Central unrounded	ü, ö, -, a	Affricate	j
Back rounded	u, u̍, o, o̍,	Nasals	m, m', mw, n, n', ng
		Trills	dr, r
		Laterals	l, l'
		Semivowels	w, y

Conventional phonetic transcriptions are given in brackets following the symbols proposed for the new Marshallese orthography. English comparisons of sounds are only approximate. Marshallese vowels are "pure," i.e., are not followed by glides.

i	[i]	ee in beet.
ï	[I]	i in bit.
ë	[ɛ^]	between i in bit and e in bet.
e	[e, ɛ]	e in bet, or a in bay.
ä	[æ]	a in bat.
ü	[ɨ]	like oo in moon, but without lip rounding.
ö	[ʌ]	o in above.
-	[ə]	(excrescent), usually like a in above.
a	[ɑ, a]	a in father; in some words, like a in Boston can't.
u	[u]	oo in moon.
u̍	[ᵘo̱]	like o in snow, but with more lip rounding.
o	[o]	o in snow.
o̍	[ɔ]	o in General American off.
b	[b, p]	initially and medially, like the b's in baby; finally, like unreleased p in lap.
b'	[bʸ]	palatalized, like b in bugle.
bw	[bw]	like bw in fast pronunciation of barbwire.
t	[d, t]	initially and medially, like the d's in daddy; finally, like unreleased t in let.
k	[g, k]	initially and medially, like the g's in go-getter; finally, like unreleased k in pick.
kw	[kw]	qu in quick.
m	[m]	m in may.
m'	[mʸ]	palatalized, like m in mule.
mw	[mw]	like mw in fast pronunciation of tramway.
n	[n̺]	like n in net, with tongue just back of the teeth.
n'	[n]	between n in no and ng in sing.
ng	[ŋ]	ng in sing.
j	[dž, tš]	initially and medially, like the j's in Jack Johnson; finally, usually like ch in much.
dr	[ř̺]	trilled r, with tongue tip close to the teeth.
r	[ř]	trilled as in Spanish, or in some pronunciations of three.
l	[l]	initial l in little.
l'	[ɫ]	final l in little.
w	[w]	w in way.
y	[y]	y in yes.

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ATOLL RESEARCH BULLETIN

No. 11

Land Tenure in the Marshall Islands

by J. E. Tobin

Issued by

THE PACIFIC SCIENCE BOARD

National Research Council

Washington, D. C.

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FIGURES

PREFACE

This report is the result of research in the field while the author was employed by the Government of the Trust Territory as Anthropological Field Consultant for the Marshalls District, August 1950 to August 1951 and from October 1951 to the present date.

It is felt that the information obtained will be of immediate practical value to those concerned with adjudication of land disputes and other analogous problems.

ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to Mr. Harold J. Coolidge, Executive Secretary of the Pacific Science Board of the National Research Council, Miss Ernestine Akers, and others of that body; Mr. Leonard Mason, Associate Professor of Anthropology of the University of Hawaii; to the Office of Naval Research and to the officials of the Civil Administrative Staff of the Marshall Islands whose assistance and encouragement made this research possible.

Special appreciation is owed: Jowej, Dwight Heine, Lokrab, Raymond DeBrum, Jetnil Felix, Lanmoj, Kabua Kabua, Litarjikit, Kondo S., and other Marshallese friends, without whose cooperation this paper could not have been written.

J.E.T.
Majuro
3-11-52

Land in the Marshall Islands is placed in many categories, each with its own descriptive name and rules of inheritance. The land is of paramount importance to the Marshallese people whose agricultural economy is based on copra production and much of whose diet comes from their land. This land area is so small--74 square miles scattered over 29 atolls and five islands throughout 375,000 square miles of ocean, that it is patently precious to its 11,000 inhabitants, each of whom is born with land rights.

The Marshallese system of land tenure provides for all eventualities and takes care of the needs of all of the members of the Marshallese society. No one need go hungry for lack of land from which to draw food. There are no poor houses or old peoples' homes in the Marshall Islands. The system provides for all members of the Marshallese society; it is, in effect, its social security.

The Marshallese have an attitude of security which is undoubtedly due to a great degree to their system of land tenure. Despite the fact that they have seen three foreign powers take over their islands--German, Japanese, and American, they still have possession of most of their land, unlike the unfortunate indigenes in many other areas of the world.

The present policy forbids sale of land to non-indigenes and, at long last, steps are being taken to return lands occupied by American forces during the war and to pay retroactive rent for their use.

It is anticipated that former Japanese Government lands and land seized by the Japanese for military installations will be made available for the use of the Marshallese people. Other land needed for U.S. military and Civil Administration use, a relatively small amount, may be leased or purchased from the owners. High level policy in regard this important matter is undecided, however, at this writing.

Although the Marshallese system of land tenure may seem overly complex, it has developed to meet the needs of this particular group of people and is an integral part of the culture. Any radical change by outsiders would disturb the society and do irreparable damage--as any student of social-anthropology well knows.

Future administrators would do well to respect this system of adjustment to the environment which the Marshallese people have evolved and should allow any changes in the system of land tenure to come from within the culture. The U.S. Naval Administration, in accordance with the Trusteeship Agreement, has on the whole respected indigenous customs and has not attempted to force the Marshallese people into an American mould or to drastically modify the culture. It is hoped that the future administrations will follow this wise course.

MARSHALL ISLANDS

DISTANCES BETWEEN MARSHALL ISLANDS

UJILAN̄ to MILE -- 700 miles EBON to BOKAK -- 600 miles

Figure 1.

PHYSICAL DESCRIPTION

The typical Marshallese land-holding or wāto consists of a strip of land stretching from lagoon to ocean and varying in size from about one to five acres in extent. Each wāto has its own name and history.

Sometimes the wāto may be broken up into two or three wāto(s) with transverse boundary lines. The boundaries, kōtan wāto are marked off by lilies, red shrubs, or frequently by slashes on coconut trees. These markers are called kakōlle.

The extended family (bwij) members may live on the wāto or merely make copra on it and use its food resources: coconuts, breadfruit, pandanus, arrow root, taro (mainly in the Southern Marshalls) and fish from the adjacent marine areas, if they possess more than one wāto as is usually the case. On most of the islands, the people live on their wāto(s). The structures found are usually a cook house, one, two, or three sleeping houses, and a copra drying shed.

The houses are mainly constructed of native materials with sheet metal and salvage lumber used in varying degrees throughout the islands. The sleeping house area is covered with small coral stones from the beach--ionle in Rālik, iole in Radak. These serve as drainage and prevent the area around the house from becoming a morass during the rains. This permeable covering is renewed regularly by the women of the household. This was the typical household arrangement prior to the coming of the foreign regimes.

When the Germans and later the Japanese set up their capital at Jabwor in Jaluit Atoll, people from all over the Marshalls were attracted to the "Big City" for various reasons. Those who did not have land or relatives in the atoll were forced to live in large "guest houses" each of which accommodated as many as sixty people, i.e., Arno house, Wotje house, Namu, Ailiñlaplap, etc.--almost all the atolls. These were of wooden construction--ca. 40' x 60' in dimension. The traditional pattern of living was changed by this congregation of people from different atolls in large population centers.

Although the beehive metropolis of Jabwor was destroyed by American bombers, the "guest house"--communal quarters type of dwelling, was perpetuated on Majuro Atoll which became the new seat of government under the American regime. Here, two large former Japanese army barracks are used by the Arno Atoll people and the northern Radak people respectively. Another large house is known as the Mille house and used by the people from that atoll. Still another group composed of individuals of mixed Gilbertese-British-German-Marshallese ancestry, in varying combinations, occupy a group of houses known as the "Gilbertese Village".

The "villages" on Majuro and Kuajlen constructed by the Naval Administration for its employees represent another change in the traditional pattern of life. The household routine remains relatively unchanged in the new type surroundings except that living is done in closer proximity than before. Cook houses, bath houses, and benjo(s) are shared by all who live in the communal houses and "CivAd Villages".

The CivAd [Civil Administration] center of Majuro is atypical also in that a "squatters'" town has arisen on Jarej (Rita), one of the islands adjacent to the CivAd center. Many Marshallese, attracted to the administrative center by much the same motives that attracted people to Jabwor in the Japanese period, have occupied abandoned quonsets or have built houses of their own of salvage material. A small quasi-"shanty town" has arisen on the island, perpetuating the Japanese acculturative influence of Jabwor. Spoehr gives an excellent account of an acculturated Marshallese community in Majuro. (2).*

Aside from a few atypical communities, the pattern of land usage remains as it was before the advent of foreigners except, of course, that the large villages have added stores, council houses, dispensaries, and church buildings. The system of land tenure and usufruct has changed but slightly despite the acculturative forces of three different regimes.

LAND USE

Members and associated members of the _bwij_ (lineage) work the land, clearing it of underbrush and performing other tasks necessary for the simple type of agriculture practiced in these low-lying coral atolls with their limited resources. In some instances people will be allowed to work land not belonging to their lineage and when lineage members do not require its use, i.e., when they have more than enough land for their own needs or want to help some less fortunate person.

The head of the lineage (_alab_) is in charge of the land and workers on the land, and a share of the food produced on the land as well as a share of the money received from copra sales is collected by him. The _alab_ represents his or her lineage in their relations with other members of the society, the _iroij_, and, today, as a member of the atoll council, _vis-a-vis_ the representatives of the American administration.

The _iroij_ (paramount chief) also receives a percentage of the money received for each pound of copra produced on land in which his suzerainty is recognized.** This share varies, ranging from 1 1/2 mills in part of Ralik to 1 cent in the Radak chain depending upon the amount of copra potential of the atoll or island and the attitude of the people toward their _iroij_. "First fruits" and a share of the food taken from the land and sea are also presented to the _iroij_, formally and informally. In Radak where the position of _iroij erik_ (little chief or king) still exists, the _iroij elap_ gives that subordinate intermediary a regular percentage of the money he has received from the _alab_ in return for services rendered as his representative over a certain area.

* See Bibliography

** Except on Ujilañ Atoll, home of the displaced Enewetak people. The pattern is different here in that each of the two _iroij lablab_ has an island and a _wāto_ of his own which he works with the help of the _kajur_. He does not receive income from any other land. This same pattern was followed on Enewetak.

Here we have a system of land use roughly analogous to the feudal system of medieval Europe ... a stratification of individuals with reciprocal duties and obligations as well as privileges.

MECHANICS OF DIVISION OF COPRA SHARE

The cash crop, copra, is sold by the individual producers to the copra buyer on the atoll or island or more often to the local general store which is usually a cooperative enterprise owned by all or a large segment of the atoll population. After the iroij share (which varies) has been withheld by the alab, his share, usually 30% of the total cash, is retained and the remainder turned over to the dri jerbal ro (workers). The senior dri jerbal under the alab may keep all of the cash and give the other workers spending money, clothes, food, etc. whenever they need it, or he may distribute the cash on a per capita basis to those who have actually made the copra. The former is the general method of division of proceeds from copra sales.

Sometimes the alab may keep all of the proceeds less the iroij share and allow the workers to do the same thing with the next copra sale. The workers may also follow the same procedure rather than attempting to divide the money up regularly with the alab, this being especially advantageous when there are a large number of workers on a small piece of land.

Although there are some deviations from this pattern, the recognition of the interests of iroij and alab are manifested by the general adherence to the payment of the share.

DEVIATIONS FROM THE GENERAL PATTERN

The most notable exception to the general pattern of land tenure is the atoll of Likiep owned in fee simply by the descendants of two European adventurers who purchased the entire atoll from the iroij lablab of Northern Radak (JURTAKA) in 1877, with all rights and privileges appertaining thereto.

The land is worked by these "mixed-blood" descendants and a larger group composed of descendants of the original inhabitants of the atoll and others brought in from neighboring atolls. This latter group produced copra on a share-crop basis.

Relationships between the two groups have been strained for years, the "owners" complaining of absenteeism and non-production and the workers complaining of peonage and oppression. Investigations were made of this situation, and a working agreement was negotiated early last year. Conditions seem to have been ameliorated; however, as was anticipated, complete mutual satisfaction and accord do not prevail on Likiep today. This is a salient example of the problems created by the intrusion and implementation of foreign concepts of land tenure into an indigenous system.

Before the turn of this century, the twenty or more inhabitants of Ujilan Atoll were forced to leave their atoll forever to make room for a German copra plantation. They went to Jaluit and Eniewetak; their descendants are dispersed throughout the Marshall Islands today.

Large scale alienation of land occurred again during the post-World War II period when the inhabitants of the atolls of Enewetak and Bikini were required to leave their atolls which became testing grounds for atomic warfare. The Enewetak people, transplanted to the uninhabited but much smaller atoll of Ujilañ, have been able to make a fairly successful adjustment to a less-favorable environment and have modified their traditional land tenure system in their new home. (See APPENDIX).

The Bikini people, on the other hand, have not been able to make a successful adjustment, due principally (in the opinion of this observer) to unfavorable ecological conditions. Kili, their new home, is a small island, limited in land area and lacking the natural resources afforded by a lagoon environment. Kili is isolated from the rest of the Marshalls many months of the year due to heavy surf, another factor for discontent.

The land tenure pattern on Kili differs markedly from that which prevailed on Bikini. A communal type of land tenure prevails in which the former iroij lablab (king) of Bikini is not recognized.

The traumatic exodus, the limited land area, the personalities of the iroij involved and his heir, ill-advised statements by outsiders, and erroneous press releases, were some of the factors responsible for discontent and change in the socio-economic pattern.

The general attitude of everyone concerned at this writing is one of insecurity and dissatisfaction. This unfortunate situation aside from its obvious aspect of a transplanted group in the throes of adjustment to a new environment is another excellent example of sudden change in a socio-economic system brought about primarily by external forces. For a detailed report on the removal of the Bikini people, see Mason, L., (1).

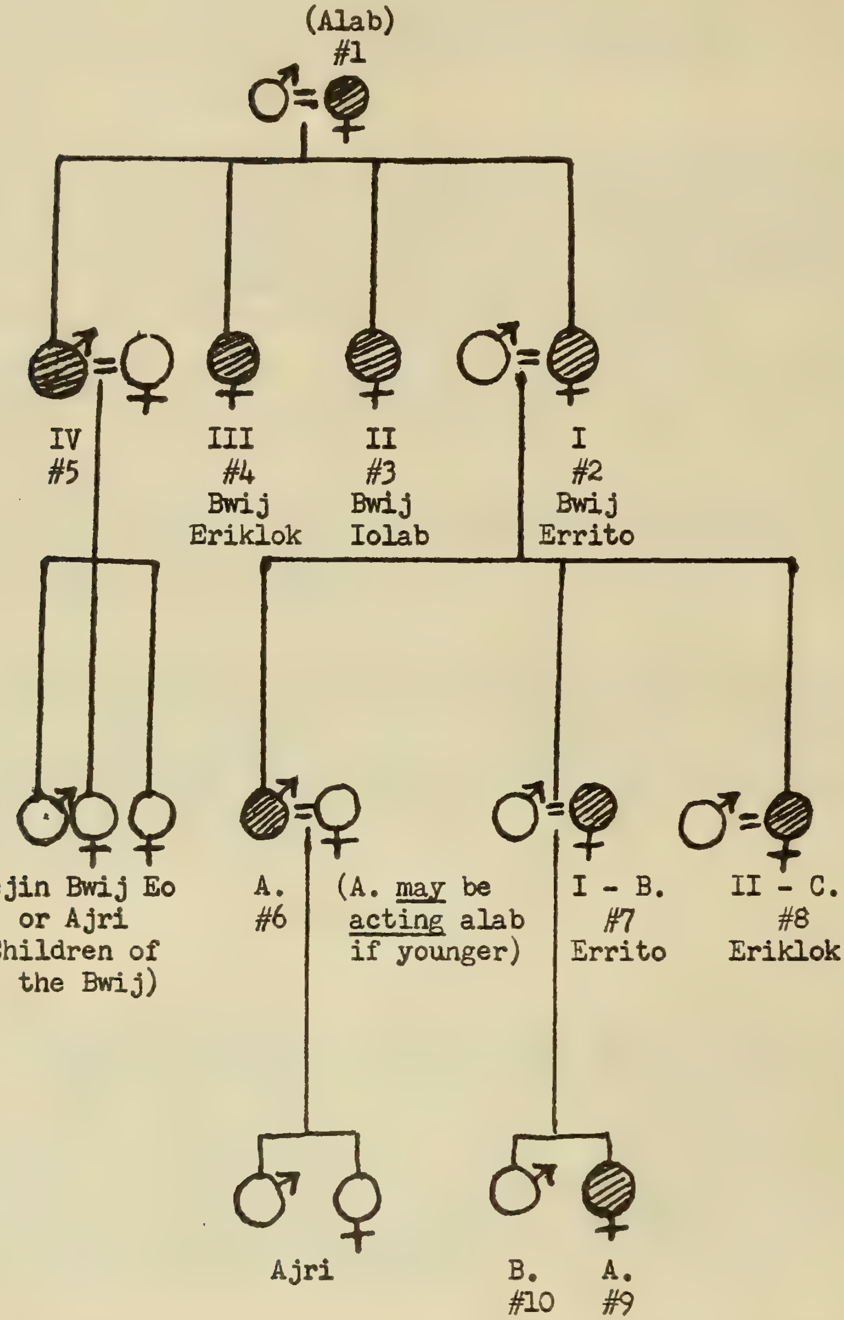
INHERITANCE PATTERN

The Marshallese system of inheritance of clan membership and of land rights (all of lāmoren-kabijukinen land and most types of burij in aje) is matrilineal. Lineage (bwij) members trace descent from a common ancestress (alab) for the purpose of claiming land rights. The original lineage normally has been split into associate lineages or bwij descended from sisters. These associate bwij are known as the older bwij--bwij errito or jiōb, middle bwij--bwij iolab (all intermediate bwij are known as bwij iolab no matter how many there are), and younger bwij--bwij eriklok, etc., according to the relative ages of the common ancestresses who belonged to the same clan (jowi).

Initially the senior sibling in the bwij--bwij eritto is alab or bwij leader followed by all of her surviving brothers and sisters in chronological order. After all of these siblings have been alab, the next generation, personified in the oldest child of the eldest female, becomes alab and is in turn succeeded by his or her siblings in chronological order. This pattern of succession continues in one maternal line of descent until the line becomes extinct; in this case, the next associate bwij in order of seniority will inherit the "alabship" and rights in a particular piece of land or lands. Every Marshallese is, as may be seen, a potential alab.

THE IDEAL INHERITANCE PATTERN OF LAND RIGHTS

BWIJ EO (THE LINEAGE)



II, III - Lineages will inherit land rights in succession - "in toto" if the "bwij" senior to them becomes extinct - "bwij eo elot".

-- Cross hatch -- maternal line of descent of a lineage.

Figure 2.

Although theoretically, relative age is the determining factor in succession to the position of leadership, actually a younger brother will assume all of the duties and responsibilities of the position from an older sister who by virtue of seniority is alab. He will become alab "de facto" but she will remain alab "de jure" and will be respected and deferred to as alab. Her brother will bring her the alab'(s) share of the produce of the land but will relieve her of all of the burdensome duties connected with the position, e.g., iroij Kabua Kabua of Rālik has three older sisters, but he assumed the alab position because he is a man. After he dies, his older sister remaining will assume the position of alab, followed by her eldest child, in the pattern previously described.

Males assume this trusteeship position; are alab first unless the women are very strong or have no male relatives to take over for them. If the male who inherits the alab position is too old, feeble, or otherwise incompetent, the next in line of succession will assume the responsibilities of the alab; will be in effect, the representative or regent for the alab. The alab will be recognized and honored as such by his own people, however, if the whole bwij (maternal lineage) becomes extinct (bwij elot) which has happened, e.g., Ralik iroij, the alab or iroij positions may be inherited patrilineally for the one generation, from fathers to sons and daughters in chronological order as described previously, after which they pass in matrilineal line of succession. This is the ideal pattern of inheritance and is recognized as the mantin ailiñ kein (the Marshallese custom) and is followed in the main. However, as in other cultures, the custom is sometimes honored in the breach. Deviation from the accepted custom is the basis of disputes, several of which are burning issues on various atolls today.

PATRILINEAL USUFRUCT RIGHTS

Although land rights, with very few exceptions are inherited through the maternal lineage, individuals are not excluded from usufruct rights in their paternal lineage land. Even though an individual may never become leader alab on his father's lineage land (unless the entire paternal bwij and all associated bwij become extinct), he does have the right to live and work on his father's land. These use rights are inherited patrilineally by succeeding generations, each of which has a descriptive name. (The same terminology is used for titles of individuals of iroij descent to indicate the amount of royal "blood" possessed by the individual title holder.)

1st generation	of	ajri	(children)	of	the	paternal	bwij-bwirak
2nd generation	"	"	"	"	"	"	lajibjib
3rd generation	"	"	"	"	"	"	jibtok
4th generation	"	"	"	"	"	"	jiblok
5th generation	"	"	"	"	"	"	jibbotto
6th generation	"	"	"	"	"	"	jibbinaretto
7th generation	"	"	"	"	"	"	tibjer

The ajri are allowed to live on and use their paternal land if they are cooperative and do their share of the work. Shirkers and trouble makers and those who do not give the alab his copra share or refuse to make ekkan, etc., may be removed by the alab of the particular land involved, however. These rights may be extended to include the seventh generation, tibjer, but are usually taken advantage of only as far as the fifth generation; the ajri rights become weaker with each succeeding generation and are absolutely concluded with

the seventh generation, tibjer , which translated means "depart from glory".

Individuals usually forego their usufruct rights on the paternal land before many generations have passed. They are usually satisfied with the use of their maternal bwij lands and their spouse's lineage lands.

This system operates to equalize land rights, prevent over-crowding and serves primarily to strengthen the in-group feeling among relatives.

ADOPTIVE RIGHTS

Adoption of children or kōkajiriri (v. and n.),(rough translation: "look out for the child") has always been a common practice in the Marshalls. Adoption here, however, does not mean alienation of the child from his biological parents as it usually does in our culture. The Marshallese child becomes a part of another extended family group but also retains his ties, emotional and otherwise, with the biological parents and other bwij relatives. The child may reside with either the foster or biological parents, or with both at different periods, as is usually the case. This pattern of extended relationships obviously makes for a greater degree of emotional security as far as the adopted child is concerned.

An adopted child, kōkajiriri, is also described as kanni lujien (rough translation: "stomach food"), i.e., the child will be eating the same food as his foster father and from the same land; i.e., he is intimately connected with his foster father.

Adopted children are allowed the right to work on and enjoy the benefits derived from the land with the permission of the alab and the bwij.

Kōkajariri may remain on the land after the foster parent dies. The children of the kōkajariri also have rights in the land which become progressively weaker with ensuing generations. These rights must also be confirmed by the alab.

The adopted child possesses much the same rights as the biological children except that he may only become alab of land of the bwij into which he has been adopted upon the extinction of all bwij relatives. A case is now pending on Majuro in which an adopted son of an alab now deceased, the last of her bwij (bwij eo elot), claims to be alab of his foster mother's bwij lands. His claim has been contested by other relatives of the deceased alab.

In addition to the rights acquired by adoption, the kōkajariri also retains his birthright in his bwij land. The adopted child is also under obligation to his foster parents and regards them as jemma (father) or jinō (mother) as the case may be, giving them the same respect and loving care in their old age that is owed and given the biological parents, e.g., "A" was adopted by "B" and his wife when he was a small child, in 1899. The biological father and mother of "A" went to another island in 1904 and remained there for eight months; during this time "B" cared for his adopted son. The father of "A" built a house nearby his own home for "A" and his foster parents with whom the latter lived most of the time even after his father and mother returned from their trip. He was not alienated from them or any other of his biological relatives, however, but retained a close relationship with them.

In the ensuing decades, "A" and "B" maintained a close father and son relationship. "A" recently brought his now aged foster father to live with him on Majuro and has assumed the responsibilities for his care although "B" has four grown children of his own. This one example shows the differences in Marshallese and Western concepts of adoption.

Individuals who possess the inherited rights in their bwij land have unquestioned usufruct rights and may even become alab. Ajiri or those who possess paternal rights are considered to have less right in the land. Kōkajariri, adopted children, are considered to have fewer rights than the members of the bwij or the ajiri.

USUFRUCT RIGHTS ACQUIRED BY MARRIAGE

Residence after marriage is neither strictly patrilocal or matrilocal, nor is there a regular periodic bi-local residence pattern as in parts of Melanesia. A man may live and work on the bwij land of his spouse or vice versa. Matrilocal residence, however, is considered more desirable in view of the fact that the interests of the offspring are bound closer to the maternal bwij land, where someday they may become alab and where they possess "real" dri jerbal rights.

Marshallese have been marrying into other atoll groups for centuries. This process has become progressively accelerated with improved transportation and communication. Opportunities for marriage outside of the home atoll have increased tremendously and today many Marshallese possess land rights in widely separated areas throughout the Marshalls. This, of course, has done a great deal to break down atoll ethnocentrism.

If a married couple should reside on the wife's bwij land and the wife should pre-decease her husband, the husband has the right to remain on the land providing there are children; in that case, the widower may not be evicted even if the alab should so desire. The offspring (who have a vested interest in their bwij land) look out for their father's welfare and help him to remain on the land.

If there are no offspring, the widower does not have a real claim and the alab may evict him or allow him to remain at his discretion. The latter course is usually followed unless the widower is a trouble maker or shirks his responsibilities. Informants have never heard of a widower or widow being evicted from their deceased spouses' bwij land. In most cases, the in-laws want them to remain. If a widower should remarry to someone outside his deceased wife's bwij, they both may remain on the land, at the discretion of the alab, but this is not usually done.

WILLS-- KALLIMUR (WILL OR PROMISE)

In pre-contact times the iroij would, if they felt that their demise was imminent, call their people together and name their successor, normally following the accepted custom of inheritance.

The German government started to register wills and the Japanese government insisted that everyone, iroij and kajur alike, should make a properly registered and documented will. This edict was complied with in the main during the Japanese occupation but fell into abeyance after the Japanese were expelled from the Marshalls. Since that time only a few individuals, mostly iroij, have executed written wills.

RENTALS

The concept of rental of land or houses was non-existent aboriginally. This concept was introduced by foreigners who wished to acquire sites for their commercial ventures, and who did so.

Transactions of this type involving Marshallese alone have been very rare. In fact, only one such case is operative today. This case occurred very recently and has political motivations rather than a mere desire for monetary gain.

The land involved had been rented previously to a Japanese entrepreneur. Interestingly enough in the recent dispute, the alab involved, in pressing her claim for rent, made the distinction between land used for business purposes (bakery and store) and that part of her land being used for dwelling purposes. Rentals were demanded for land falling in the former category only.

An individual who has obtained the alab'(s) permission to erect a house, etc., not on his own bwij land may from time to time voluntarily bring food to the alab of that land. However, the concept of rent "per se", is not implied.*

ENCLAVES

TREES (kān)

Individual trees may be given to a person outside of the bwij by the alab. Nearly every wāto on Majuro has trees (coconut mostly) that have been set aside for Protestant Church use. There are also many gifts of this kind on Arno and Ebon and other, but not all, of the atolls. Many of the government schools have received trees also. Trees are called ni kān (coconut tree) or mā kān (breadfruit tree), etc., depending on the type of tree. The affix kān means tree or stump.

Only the recipient may use the produce of the tree involved. He may give the alab or others permission to use the tree in his absence, however. A gift of this sort may revert to the donor upon the demise of the recipient, (it is considered a transaction between two individuals) or the recipient may be allowed to retain the kān at the discretion of the alab.

* See ADDENDUM

TARO PATCHES (sing. bwil; pl. bwil ko)

A bwil or taro patch within a wāto may be given to individuals outside of the bwij or it may be retained within the bwij, at the discretion of the alab. An example of the different categories of bwil which may be found on one wāto may be seen on Eram wāto on Ebon Atoll, one of the southern Marshalls, where the largest amount of taro is to be found. Viz: 1. One bwil is assigned as iroij bwil (bwil an iroij). It is tended and cleared by the dri jerbal but is not harvested except when the bwij makes special ekkan (ar makie)-"our (bwij) alone", to the iroij. The bwil produce is not used for any other purpose, and bwil an iroij are inherited by the heir of the iroij.

2. One bwil assigned to "A" who is a kōkajariri (adopted child); she tends the taro patch and harvests the taro for the use of herself and family. The alab will not touch this taro patch; if he should do so (cultivate it, etc.), it would imply that he wished to evict the person to whom it had been assigned. (This is also true of land in general). A new alab will subtly signify his approval of previous assignments to bwil and will ratify same by saying to the incumbent: "I would like a basket of taro from your bwil."

3. Another bwil was assigned to "B" and his brothers. Before the turn of the century, "B" had been born into a lineage holding Eram wāto. At that time, male and female twins were considered as being incestuous, having spent the prenatal period in juxtaposition--within their mother's womb. "B" was, unfortunately, one of these. According to custom, his twin sister was allowed to live ("to become alab") and "B" was buried alive. He was exhumed immediately, however, by a pitying neighbor who reared him as her kōkajiriri (adopted child). When "B" had grown to young manhood, "C", his female cousin, invited him back to the bwij lands. She had attended the Protestant Mission School on Kusaie and disapproved of the rejection of "B" by their lineage. "C" was the senior female in her lineage and next in line to be alab, consequently very powerful and much respected. "C" allocated a bwil and the dri jerbal rights in two of their bwij wāto(s)to "B". Although "B" could never become alab because of the "incestuous" circumstances of his birth, he was tacitly accepted within his bwij by the other bwij members. When "B" died, his bwil was inherited by his son who holds the use rights to it today.

4. There are six other bwil or Eram wāto, the taro of which is used by the dri jerbal of the wāto. An alab may reserve all of the bwil for himself to be used for ekkan. In this case the dri jerbal will not use the produce from the taro patch unless the alab gives them explicit permission. This is not the case on Eram wāto, however; the alab allows the dri jerbal free access to the bwil which was not true of some of his predecessors.

5. Another type of bwil is that which is exchanged for another bwil or a good breadfruit tree (mā kān), This is usually done to cement ties of friendship and marriage, e.g., about thirty years ago a bwil on Eram was given to "C", a man who had married into the bwij, in exchange for a breadfruit tree located on "C"'s bwij land. The taro from this particular bwil was considered to be the property of this individual and respected as such. Conversely, the fruit from the particular breadfruit tree was considered to be the exclusive property of the alab and people of Eram.

About nine years ago, "C" commenced "stealing" the breadfruit from the tree and later signified his desire to regain his former property by climbing the tree and openly stripping it of its fruit. This angered the people of Eram,

who felt that "C" had broken tradition and affronted them by taking breadfruit from the tree while continuing to use the bwil and then seeking the return of the tree (which was a very good one).

6. Temporary usufruct rights: a section of a taro patch may be allocated as a source of food for people who are visiting an island for a short while (this is not an outright gift), e.g., Namrik Atoll people visiting their children who were attending the Japanese Government School at Ebon were afforded this privilege.

7. Gift, as kitre to one's wife: taro patches may be given by a man to his wife as kitre. There are some instances of this on Ebon, Likiep, and Mejij, etc. Permission of the alab and bwij must be obtained before a bwil may be given as kitre. Failure to do this may cause serious disputes, e.g., on Mejij, an iroij who had worked a taro patch without any assistance from his relatives gave the bwil to his wife as kitre three years before he died. This was done without consulting his bwij. After he died, his bwij contested this gift. The dispute was finally settled amicably a few months ago. The bwij agreed to allow the childless widow to use the bwil until she dies, at which time it will revert to the bwij. The bwij may allow the decendants of a woman who received kitre to retain possession of the taro patch involved. Non-Mejij Marshallese who heard of this case stated that the woman's bwij is entitled to possession of this bwil according to custom.

REEF RIGHTS

Throughout the Marshalls the reefs were claimed by the iroij as emo or personal property if the fishing was good around them. The iroij would declare: "Wur in buruan." (My own reef) or else "Wur in iroij" (reef of the iroij). After this tabu was instituted, no one else was permitted to fish that particular reef on penalty of death or expulsion from his land. In 1934 the Japanese authorities "broke the tabu" by declaring the reefs open to everyone. From then on everyone who so desired has utilized these once forbidden fishing grounds.

These reef areas were usually near the entrance to the lagoon where fish are especially plentiful, e.g., within Arno Atoll about one half mile from the shore of Malel Island lies a reef called "Moen". This reef is the habitat of many tuna and other fish which feed around it. The tabu described previously applied here also. The reef fishing on Ebon is very good, several isolated reefs are the habitat of a large fish "ellok", whose flesh is considered particularly good. There were five wur in iroij here: Tokāinbarao, Wodrenlap--(translation: big reef), Tokimkil, Buruan Lewoj--(translation: Lewoj, an old Ebon iroij, wants the reef), and Naminaujedr.

These choice fishing spots were reserved for the iroij lablab alone as previously described. Other people were afraid to disobey the tabu until it was lifted by governmental edict. Small islands were also occasionally tabooed, e.g., Kaben, a small island with a few trees on it on Wotto Atoll, was taken by the iroij for his personal use because of the abundance of coconut crabs on it.

On Likiep Atoll a stretch of beach on the main island extending from the site of the Catholic Mission to the Northern tip of the island, a distance of about 2000 meters, was forbidden territory. It was emo to fish within thirty

yards of the shore along this area, which is the habitat of large schools of tou (mackerel). The "owners" of Likiep considered themselves as iroij and instituted this prohibition in German times. Here again the tabu is not enforced today. Emo (forbidden) fishing sites were in existence on every atoll.

FISHING RIGHTS

According to custom, the property rights extended out to the area where people stood, usually waist deep, in order to fish with a pole. Momo and rijo were the fish commonly sought. These rights belonged exclusively to the lineage, bwij, whose land holding, wāto, bordered the marine area.

This custom continued until 1934 when the Japanese authorities declared that all marine areas, up to the high water mark, belonged to the Japanese government. Marshallese informants believe that this change was made in order to allow the Japanese to claim logs, barrels, lumber, and other items of flotsam and jetsam. These objects were highly prized in this area where heavy timber was scarce and especially so in pre-contact days when metal was only obtainable from the above mentioned sources.

The iroij lablab of the particular area into which these materials drifted claimed exclusive rights to them. The loss of royal prerogatives and attendant revenue was, of course, resented by the iroij, who were powerless to prevent it, however. This break with tradition has continued under the American trusteeship and is apparently accepted by everyone today.

GAME RESERVES--"BIRD ISLANDS"

The Northern Radak atolls of Bikar, Bokak (Taongi), Tōke, the island of Jemo, and the islands of Erik and Luij in Erikub Atoll have been used from time immemorial as game reserves. These areas are the habitat of myriads of sea turtles and nesting fowl. Periodically, turtles and turtle eggs, birds and their eggs were taken, as described later (see emo).

Due to the scarcity of water supply, these islands have never been regularly inhabited. The Germans used this fact to justify the seizure of the atolls of Bikar and Bokak as government property. The Japanese took them over with all the other German government properties. They were not exploited by either foreign power, however, and the Marshallese from Northern Radak have continued to utilize their resources.

Lañmoj, the iroij lablab of northern Radak, whose ancestors owned the two atolls, claims personal title to Bikar and Bokak as mo land and has stated that the German claims were invalid. This writer agrees with the Marshallese position that land used as a source of food supply, etc., should not be alienated from its owners merely because it is not regularly inhabited and cultivated.

It is recommended that the United States Government withdraw all claims to Bikar and Bokak in favor of the Marshallese who feel that they have never legally lost their rights in them.

INDIGENOUS ATTITUDES TOWARD THE LAND

Land is considered to be the most valuable asset to the Marshallese who are so dependent upon it for their day-to-day existence. Land disputes have been and still are the cause of almost all family schisms. People are always plotting to obtain more land, by marriage today and by warfare, marriage, and black magic in the past.

Black magic, ekabel, was sometimes used to kill off the older members of the lineage, particularly in the case of the iroij bwij: "Rubrub ñon ro nejin" (destroying the obstacle to her children), i.e., removing the obstacle (person) to her children's succession to land rights. A non-relative is always asked to make the magic. It is believed that the illness or death sought for the enemy will "boomerang" and also afflict the person who performs the magical rites if he or she is related to the proposed victim of black magic. According to informants, ekabel, is sometimes performed today.

Land is regarded as sacred "something to fight for and die for" and has been, as far as may be ascertained, sold or given away to outsiders only because of fear of either physical or moral force. A salient example of this attitude was observed recently at Majuro. A rumor had been circulated to the effect that the United States Government was planning to reimburse the owners of the land upon which the administration functions are located by giving them pieces of former German-Japanese government lands located in Majuro and nearby atolls. This rumor created a tremendous amount of anxiety, insecurity, and distrust on the part of the individuals concerned. This writer was deluged with queries as to the validity of the rumor. The concensus of opinion of the Marshallese involved was: "We will never willingly accept any other land in exchange for our lineage lands."

They will not willingly accept complete alienation of their land. The individual Marshallese is fully aware of the particular categories into which his lineage lands fall and what rights he possesses in them. Genealogies, both royal and commoner, are traced back in some cases ten or more generations and many of them have been written down, are carefully preserved by their owners, and used as evidence to support claims in land disputes.

The younger generation of Marshallese, however, those under thirty or so years of age, as a whole are not fully cognizant of the less basic concepts and customs of land tenure.

CONCEPTS OF LAND OWNERSHIP

In the pre-contact period, the iroij lablab (the senior ranking member of the senior lineage of the ruling clan (jowi) was the acknowledged owner of all the land and moveable property in his realm in a socio-economic system roughly analogous to the feudal system of medieval Western Europe or closer at hand, to the social system of pre-contact Polynesian cultures with the reciprocal rights and obligations of all classes within the framework of the society. The subjects of the iroij could not be evicted from the land without good reason, however, (mainly for offenses against the iroij himself), and their rights were as a rule, respected by the iroij. The more commoners (kajur) an iroij had in his

realm, the more power he possessed--a large reservoir of human beings to draw upon for labor and warfare. (The word kajur itself means power). It was therefore manifestly incumbent upon the iroij to treat his subjects with consideration and retain their loyalties.

A regular channeled tribute system, ekkan, was adhered to by the subjects of the iroij. In the latter part of the nineteenth century with the development of copra as the cash crop, the share of the iroij and the people who produced the copra was established. (See LAND USE)

The concept of iroij ownership of the land apparently continued and was unquestioned until Japanese times, prior to World War II. At that time the Japanese introduced the concept that the iroij owned the land and the kajur owned the trees growing upon the land. This was probably done to facilitate acquisition of the land needed for military bases and installations.

Some informants believe that the new concept was a result of Japanese misunderstanding and jumping at conclusions. It is alleged that when the Japanese officials queried as to who planted the trees, the Marshallese replied: "The kajur did." The Japanese then supposedly assumed that the trees were the property of the kajur who had planted them. As a corollary, we may logically assume that the iroij upon being questioned, informed the Japanese that the land belonged to the iroij, as per custom.

This foreign concept of separate ownership title to the land and of all of the trees growing upon the land was implimented by the Japanese officials who paid some of the iroij and alab(s) involved for land and trees respectively. The foreign concept of division of ownership plus the fact that the foreigners beginning with the Germans had supplanted the iroij as the supreme authorities were undoubtedly contributing factors to the gradual shift of orientation which has continued to the present time and which was accelerated by the social disruption attendant upon World War II and the American invasion and occupation of the Marshalls. The concepts of "liberty", "freedom", and "democracy" were freely disseminated by the new rulers without, it is believed, adequate definition or explanation. This further contributed to change in attitude in regard to socio-economic concepts on the part of a segment of the population especially, as might have been expected, on the younger element who were in closest contact with the Americans.

The general attitude today in regard land rights (as far as this writer has been able to determine) is one of joint ownership of land rights with the iroij possessing certain rights and the kajur possessing other rights in the land, holding these rights as a member of a lineage (bwij) in common with the other bwij members.

The general concensus of opinion seems to be that the Japanese concept was an artificial one and that the trees cannot be separated from the land. The concept of joint ownership of land rights is stronger in Rālik than in the Radak Chain, probably because the true iroij have become extinct with a few exceptions in Rālik while the true iroij still flourish throughout the Radak Chain.

The prevailing opinion was exemplified by the actions of the last "Marshallese Congress", where representatives of the mass of the population,

the "House of Assembly", met with the iroij, "House of Iroij". At that time, this matter was debated at length. The iroij declared that they owned all of the land and were upheld by a small percentage of the older kajur. However, the majority, young and old, disagreed, stating that the land is owned by everyone.

A small anti-iroij sentiment exists today, largely composed of younger men most of whom have been closely associated with Japanese and Americans. These individuals (none of whom are organized as a group) are anti-iroij only in the sense that they are opposed to deferring to certain individual iroij. They are not against the institution of iroij per se. In fact, the desire to retain the economic prerogatives of the iroij for themselves is the principal motivation for their deviation from the norm.

At the other end of the pole are, of course, the iroij and their adherents, most of whom are the older and more conservative element. It is anticipated that the iroij position, "where disputed", will become correspondingly weaker as this older and more conservative element dies out.

It is hoped that the administration will continue the "laissez faire" policy insofar as possible in regard to the land rights situation. Any disagreements may be brought before the District Court if the disputants themselves fail to reach an amicable agreement. (This is the current available mechanism for settlement of land disputes of which there are many.) However, at this writing, only one case involving land rights has been brought before the District Court. Apparently the Marshallese are wary of legal processes that are outside of the local culture pattern and are reluctant to bring the highly important problem of land rights before an outsider. This writer has personal knowledge of many instances where land disputes have been channeled through to the traditional authorities rather than through the alien American mechanism for handling these problems.

The administration should not support one group or the other involved in land disputes; but should remain neutral offering advice to all sides if requested. This obviously requires a great deal of "tight wire walking", so to speak, but it is absolutely necessary if the governing authorities are to have the confidence of everyone and accomplish their mission. The Marshallese are watching every move that the Administration makes regarding land matters. Any ill-advised move by the administration might very well upset the present balance, causing any of those who may be uncertain and wavering in their attitudes to follow the administration's lead. It is, therefore, obviously necessary for the administration to treat all situations involving land rights with the utmost discretion. These problems should be worked out by the Marshallese people themselves with the minimum of American interference and that only when absolutely necessary.

CATEGORIES OF LAND

Land is divided into three general categories:

A. Lāmoren or Kabijukinen (rough translation: old "family land").

B. Ninnin (literally: "nurse from the breast")--land allocated by a parent to offspring.

C. Imonaje (burij in aje)--(Literally: "divided land").

The terms lāmoren and kabijukinen are applied to the same type of land, the ancestral land holdings of the maternal bwij; however, there is a shade of difference of meaning in the two terms. Lāmoren (literally: "old stone", from the lā--"beach stones", pebbles, placed around the home site, inside and out) refers to the ancestral land (earth) itself, while kabijukinen or birbir (foundation) as it is sometimes called, has a poetic connotation of deep affection and sentiment and is used in much the same way on a larger scale, as the Japanese sometimes describe their homeland by the word "Yamato" rather than the more commonly used "nippon" or as the Irish refer to "the ould sod", the Russians to "Mother Russia", etc. The majority of land holdings in the Marshall Islands belong to this category.

Burij in aje (imon aje) is the descriptive term for land that was given by the iroij for outstanding services in war and peace time. Many types of land are included in this general category each with its own descriptive name.

With the end of local warfare (during the German period) gifts of land resulting from warfare, i.e., marujinkot, waenbwe, etc., ceased. Other burij in aje such as rewards for magic, medicine, and navigation, etc., are made very rarely today. Ninnin (land given by a parent to an offspring) is still made occasionally today, however.

BURIJ IN AJE - IMONAJE - DIVIDED LAND

Imonaje (Rālik and Radak) is land given to a person who helps the iroij by nursing, bringing food, etc., makes medicine, etc. The iroij may give food, mats, rope, etc., instead of land. This is known as mweien kalotlot (goods for nursing) or mweien tiriamo (goods of sorrow) and is given by the iroij only, to anyone. The iroij may make imonaje to a kajur, either alab or dri jerbal; no one else may do so.

In the old days two men remained with the wife of the iroij at all times in the capacity of watchmen or body guards. One remained outside at all times--escorted the iroij's wife, brought food to her, etc. This functionary was called dri jutak loto (translation: "man who stands by the iroij's room). These men received imonaje land for their services. They were related to the iroij on the father's side; they were last in succession and least likely to try to kill the iroij to gain his position; therefore, the most trustworthy.

An informant acted as dri jutak loto for the late iroij lablab Murjil of northern Radak ca. 1916 to 1919. He is a cousin to the said Murjil on the paternal side. His food was given to him by the iroij. He carried a knife with him at all times but was never forced to use it. Informant stated that he had to stay awake on guard against possible attack many nights because of trouble between two iroij--Murjil and Tonuia, iroij of Airōk (Maloelap). This trouble lasted for about one year.

The person nursing the iroij as a baby is known as the dri-jutak lomalal; this person belongs to an iroij bwij, one of whose members has the honor of being the dri-jutak lomalal. The dri-jutak loto position goes to a brother or son like regular paternal inheritance, in order of seniority. The iroij always

chooses the woman he wants as wet nurse for his children from his bwij or that of his father, whether iroij or not.

Land was always given for these services; informant received land for his services. He became alab and receives the iroij erik share now but is not a real iroij erik, and he is not called by that title. There are no positions or title of this kind now, dri-jutak, etc. After iroij Murjil died (during the middle phase of the German occupation), these positions became extinct.

The offices were continued during the life time of the incumbents, from youth until their health failed and they were unable to discharge the duties of their positions. At that time, the iroij instructed the outgoing dri-jutak loto or dri-jutak lomalal to name the successor--someone he trusted in his bwij or on his paternal side as the case might have been.

Burij in aje is also used to describe land given by the iroij to refugees from an area devastated by typhoon, drought, tidal wave, etc. The iroij or leroij might allocate land to their respective spouses as burij in aje.

Inheritance Pattern:

The recipient of burij in aje, imon aje may either assign it to his bwij or to his children, as he so desires. In the latter case, all of the children will share in the use rights of the said land. The eldest of the children will become alab as per the customary matrilineal inheritance pattern.

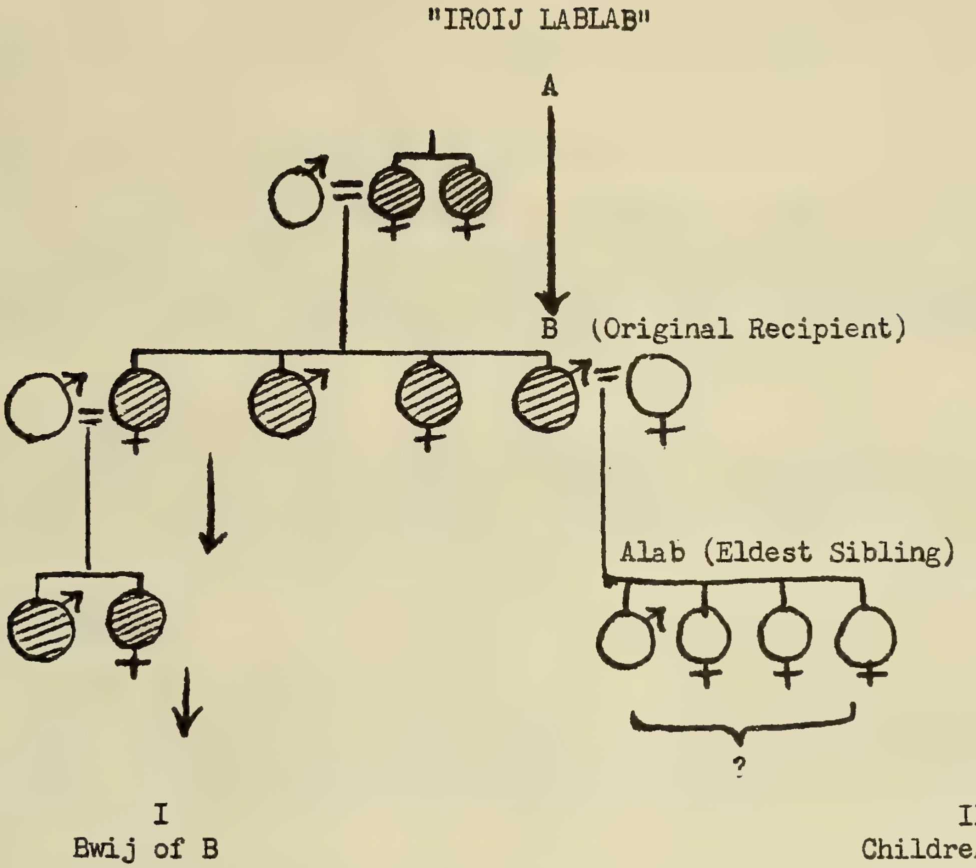
The decision as to future disposal of the land may then be made by the alab in the succeeding generations. The land may be retained within the bwij or divided again between the siblings. It is alleged that in most cases, the land is retained within the bwij. Siblings usually cooperate with each other in this matter "because they all shared the same breast".

Jikin Kolotlot--Imon Kolotlot--Jemlok (The Ending) is land given for nursing or caring for iroij or alab when ill. Given on death bed usually or prior to death when person is becoming old. Gift must be approved by the iroij elap. The recipient may be a medicine man (dri uno) who nursed the donor of the land, e.g., when iroij Tōbo was ill on Arno in 1950, many people gathered about him, as is the custom; some of them brought food to him, carried him to the outhouse, bathed him, etc. His dri uno remained near him at all times during his long illness. This functions as a sort of "sick care insurance". Land of this type is passed down through the bwij. During the German period, Kwier Island on Kwajalein Atoll was allocated to Leanmo as jikin kolotlot by iroij Jeimata and his half-sister, Libetok, upon the death of the former iroij lablab Leit. (See NOTE).

NOTE:

1. Men in kolotlot is personal property; clothing, fish hooks, money, etc., not belonging to all share holders of the land. The money, etc., is given to the eldest child to divide among the siblings. Adopted children are not included. Money may not be given to an outsider "because this creates disputes" as informants have explained. A man may leave a house, cistern, etc., to his (NOTE continued on p. 18)

"IMON AJE", "BURIJ IN AJE"



"IMON AJE", "BURIJ IN AJE" (divided land) may be allocated to either "bwij" (I) or children (II).

Figure 3.

Imon Ato (Rālik), Montutu (Radak) (come ashore to get land)--land, not an island, given to a person who adopts, nurses, guards, and cares for the child of an iroij, gives him special anointment (kokabit) with coconut oil, etc. The guardian (kwor) may be either a man or a woman and his or her bwij become kwor also. Any member of this bwij may correct the child of the iroij when he misbehaves, by beating him and pulling his hair (usually very tabu) and may stop him from fighting; i.e., they are in the position of parents to the child of the iroij, whom their bwij member has nursed. The iroij provides food for the child and the guardian. When the child has grown up, his iroij father gives the land to the guardian (kwor). Someone other than the wife of the iroij nursed the children of the iroij. People vied for this respected and lucrative position.

Enen Tutu--an island given for the above services.

The person who receives this type of land may allocate a portion of it to his children who will have dri jerbal rights only and may not become alab unless their father's bwij becomes extinct. These dri jerbal (worker) rights are inherited by their children, but the land (enen tutu and montutu) as a whole belongs to the bwij of the original recipient and is passed on through this bwij.

Jikin In Kokabit--land used as a special place in which to give magical medical treatment. It is forbidden land (emo), a restricted area. The bwirak (noble) children of the iroij use the area, not the iroij. This is one of the devices used to enhance the prestige of the bwirak; as an informant explained:

Everyone knows who the iroij is; he does not need as much mo as his bwirak offspring."

The jikin in kokabit is usually a small island, but it may be a small piece of land. In either case, the land area is not large enough to till. This land may belong to any individual but may not be used or even walked on by the "owner". The purpose of these tabus is to prevent people from seeing the magical treatment.

The bwirak were annointed to make them strong and attractive and brave in war. Sexual intercourse was forbidden--sometimes for as long as six months following the treatment. If the treatment did not prove fruitful, people

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(NOTE continued from p. 17)

son if he has built it himself. It will be very difficult to do this, however, if his brother, uncle, or other bwij members helped him to construct same.

2. Incorporeal property such as knowledge of magic, medicine, navigation, etc., is traditionally guarded jealously and transmitted within the iroij group or to individuals whom the iroij may designate. Possession of this secret knowledge has served to enhance the iroij position, adding to their prestige and bolstering their position as leaders of the society. This was especially true in the pre-contact period and immediately following, before an education (reading, writing, etc.) became available to all.

would say, "He spoiled his kabten"(head anointment), i.e., he had indulged in the forbidden sexual intercourse. These sites are still tabu although it is not certain whether or not the magical medical rites are still practiced. It is said they were up to the end of the Japanese regime.

Wuliej Lap (big grave)--the plot of land in which the iroij are buried. This area is forbidden (emo) to anyone not of the iroij ancestry, with the exception of the guardian bwij, kwor. It is believed that supernatural sanctions will automatically operate against those who violate the tabu.

This writer recently visited the wuliej lap on Mejruirōk Island, Jaluit Atoll in which lie the remains of Litokwa, Lajutok, and other Rālik iroij. Two Marshallese youths, one a member of the field party and native of another atoll (Kwajalein) and the other a local resident, refused to get within 150 feet of the small plot of ground in which the iroij are buried. The grandson of Litokwa, however, visited the graves with complete unconcern, explaining that he had the right to do so.

Ninnin (v. and n.)--land given by a father to his children; it belongs to the bwij. A man's daughter and son will only have dri jerbal (worker) rights. The bwij may not take these rights away from them.

The senior bwij member is always the alab. If the alab should try to take away the land right, the iroij will intervene and prevent it. The dri jerbal rights are passed down from parents to children from then on, but alab rights go down through the bwij. Alab and iroij may allocate this land, not dri jerbal. A dri jerbal may never allocate alab rights to another kajur. He may, however, allocate dri jerbal rights to his children--real or adopted. He may ninnin only if the bwij agrees. The alab himself may not assign bwij land away unless permission is granted by the bwij.

The alab has authority over division of food and work assignment, etc., but on land division matters, he must consult with his iroij and his bwij. He cannot do anything on his own accord in land division matters. This is true today and was true in the past, i.e., the alab is not the final authority or autocratic leader. He must consult with his lineage on these important matters. He does not have the exclusive rights in the land, e.g., an alab on an atoll in Northern Radak recently expressed the desire to evict the children of his mother's younger sister from the bwij land because they had been "too haughty", refused to bring him food (ekkan), etc. He complained to his iroij who told him that if he evicted the cousins from the land, he would be violating the custom (manit eo). The dispute was then settled amicably.

If the bwij does not concur with the desire of the alab or dri jerbal to ninnin to his children, the children may remain on the land as ajri in bwij. They will work for the alab's successor and have practically the same rights as the dri-in-bwij (people with matrilineal dri jerbal rights). The difference lies in the inability of the ajri to become alab (unless the entire bwij and associate bwij become extinct). Everyone must have the alab's permission to cut trees, build houses, etc.

After the recipient of ninnin dies, his or her children may be allowed to remain at the discretion of the bwij, i.e., the iroij or alab gives ninnin to one generation only, his son or daughter.

A lesser chief, iroij erik, may make ninnin to his kajur (commoner) son but he cannot leave him all his iroij erik rights and title. These must go to someone of iroij blood. If the iroij erik has no relatives left, the kajur child may take the iroij erik rights but not the title. "He is not a 'real' iroij erik." Cases were cited by informants where iroij erik have given a kajur child part of their lands as ninnin but not the iroij erik rights. The ninnin goes down through the children and their children.

The iroij lablab may make ninnin of special land parcels (wāto) to his children, but the bwij members are not excluded. Ninnin as may be seen is a mechanism by which a father in this matrilineal society may provide for his children. One informant stated, "Everyone likes to make ninnin because they help out their children and everyone likes to receive ninnin because they get more land."

This method of land division often creates problems; on Mejij, for example, it has been cause of disputes since German times. Some of the people who had received ajri rights refused to pay tribute or ekkan of produce from the land to their alab(s) on the ground that they had ninnin rights and did not have to recognize their uncles' authority; conflict ensued.

Sometimes the alab made the division before his death so each of his children had rights in a portion of land. The recipient generation of ninnin and their female children have dri jerbal rights in the land. The male descendants of this generation have ajri rights only. There is much of this today; especially on Maloelap, Aur, and Wotje.

Ninnin land is always given by the father to his children. The donor may be such a strong personality that he is able to go against the wishes of his bwij relatives to allocate the land outside of the bwij. There have been instances of this deviation from the norm. Most types of imonaje may become ninnin.

Morjinkot (Rālik), Bokman Mare (Radak), ("take at the point of the spear") --land given by iroij to a warrior for bravery in battle. After the battle was over, victorious iroij always called the iroij erik and alab(s), "the ones who know more than the others", together to talk it over. They sat and listened to the iroij. He would then call the men to his house and would say, "I give you (such and such a land holding)--morjinkot. Then he would pass the word to the assembled people who had come to honor him, bearing ekkan. Morjinkot was always given by the iroij only to kajur. Whenever land was given as morjinkot, the people living on the land might be allowed to remain on the land as workers for the new alab or they might be sent away and new people placed on the land. The iroij told the original dwellers on the land where to go.

The recipient could give the land to his children or to his bwij. It was not supposed to be given to anyone but a relative. The permission of the bwij had to be obtained in order to give land to son. If the original recipient gave it to the bwij, it followed the custom through the bwij. Once the land is passed down through the bwij, it must continue this way. It is up to the first recipient to decide: "He is a very important man". If it should start through the paternal side, it must continue this way; may not be changed.

This is very important but is sometimes violated and causes trouble. Sometimes, a man would give the land to his wife; this was "wrong", and was done very rarely. When land was given to the wife and from her to her bwij, much trouble started. Usually the first man who received morjinkot from the iroij gave the land to his bwij rather than to his children. A man receiving morjinkot could by-pass his brothers and sisters.

The recipient would tell the iroij how he wanted to dispose of the land he had received as morjinkot. The iroij then informed the iroij erik and alab(s) of the disposition of the land. The iroij could prevent the man from disposing of the land if he thought it was not right.

If the man's bwij had fought hard in the war, the iroij would instruct the man to leave the land to the bwij; or if the man and his son or his brothers were good fighters, the iroij might favor the paternal side, i.e., dependent upon actions in the war; which group fought the hardest. If the man had no brothers, sisters, children, or relatives on the paternal side, the land went to the bwij. Although this land is given to an individual, the bwij is included--paternal relatives also. Recipient conferred with his uncles, and they all divided the land.

A man usually had to confer with his alab for disposal of morjinkot (after he received it) even though the alab had no part in the war. The land was divided among the recipients and his siblings, only to clear and work, not to keep. The siblings were assigned to different wāto(s) if more than one wāto was given by the iroij, e.g., Lañar Island, Arno after the intra-clan (dri Mweijor) war of Tawij vs. Ujelañ.

Maternal relatives and paternal relatives both used the land. Maternal relatives have a "real right" in the land. Paternal relatives could get food from the land but did not have "real" rights in the land. After the senior bwij member died, the next senior person in the bwij became alab.

The land usually went to the whole bwij when the iroij made a morjinkot grant. All of the fighting men, dri terinae, were accompanied into battle by their female relatives who acted as "supply and hospital corps", carrying water and food for their men folk, usually in a coconut shell container. The women involved were called dri bōk bōka (person who brings a water or food container). The saying was, "They are following us to take care of us when we are hurt." The auxiliaries did not carry weapons but remained a little behind the warriors, watching and waiting for a male relative to fall wounded or dead at which time they would rush to his side to succor him or carry away his body.

The warrior's uncle would be alab on the land whether he went to war or not. The warrior was under him. After the old alab died, the alab title went to his siblings according to the customary matrilineal system, and after them, to the warrior's older brothers and sister, in order. In a case like this, the man who received morjinkot could never become alab until after his senior's demise, i.e., the benefit accrued to the bwij rather than the individual.

Ninnin could, however, be made in the first instance. The alab could make the division ajej for all of his children. This may be done generation after generation. This has been done on Mejij Island (as previously mentioned). There one may see small wāto(s) with only fifteen trees. This caused much friction. The alab divided up the land among all of the bwij members. This was last done during Japanese times. The Mejij people realized how impractical this was and have stated that they believed the practice of ninnin has been the cause of much trouble.

The children usually work the land together, and it is inherited like lāmoren land through the bwij.

A man could not allocate the land to his son alone; the bwij had to share. It was impossible for the land to be given to an outsider. On Wotje, land was given (in one case) to relatives of the mother due to extinction of the bwij. The iroij elap Jortaka turned the land over to the oldest of the mother's relatives. Informant never heard of a man giving land to anyone outside the bwij. The iroij would become angry." The land will automatically go to the next senior bwij when the oldest bwij becomes extinct, as has occured during time of war.

Waienbwe--land given by the iroij as a reward for forecasting the future. A dri bubu (magician) was attached to the iroij'(s) court and advised him as to the appropriate time for going to war, building a new house, going fishing, etc. But land was given for giving advice on war only; food, mats, etc., were given for prophesies not connected with warfare. A dri bubu was given land one time only by the iroij for past, present, and future prophesies. The dri bubu was and is a highly respected person and many tabus were and are still attached to his activities.

Informant's father learned magic from Bouliej, iroij lablab of Northern Radak, who taught his sons and grandsons. He was very proficient at bubu. In the past, the iroij knew more about magic than anyone else. However, the restrictions, especially sexual, caused the iroij to maintain a magician in his entourage. This knowledge, according to legend, was taught by two demi-gods, Lewij and Laniej, who came down from heaven and lived at Buoj Island in Ailiñlaplap Atoll for a while, teaching tatooing as well.

Waienbwe was a reward for personal services and could be ninnin to the recipient's children or could be passed on through his bwij at his discretion. The recipient becomes alab whether he is the senior member of the bwij or not. He may have an uncle or brother who is senior to him and his alab, but this man will be alab on the bwij land only. The recipient of waienbwe or kworaelem land will be an alab himself on this land.

Kwodraelim--land given by iroij to a man who sailed with him and bailed out his outrigger canoe (very hard work and necessary to keep the canoe afloat and enable it to keep underway) in war time and peace time. This type of land could be passed on through maternal or paternal side--son or daughter at the discretion of the recipient--like waienbwe. The reward of kwodraelim could be deferred until a later date. It was like waienbwe in that it was given as a reward once to an individual and was inherited like waienbwe.

Anburo (older word: kitre)--general term for presents of food, clothing, etc., given by a man to a woman before and/or after he marries her. Anburo (literally: "of the heart") and kitre ("out in the open") as opposed to bonerik (something one hides to buy the heart of the girl one loves). Kōbwōjbwōj is the new slang expression for the latter type of gift. An analogy is drawn by

informants, with two sailing canoes in a race. The paddling done by the men in one of the canoes which gives the extra advantage and wins the race is like the kōbwōjbwōj (gift) given by one of two men who are courting the same girl. The word has a slightly ribald connotation.

Taro patches are sometimes given as kitre.

Katleb--land allocated by the iroij lablab to a kajur. The word was derived from katleb (large planting), i.e., the iroij plants (trees) people on the land. "Plant the whole tree", i.e., "Plant the island, all of it, with people". Katleb means all former inhabitants were cleared off the land, no one remaining on it at time of the gift. Whenever land was given as morjinkōt (reward for bravery) after a war, the inhabitants might be sent away if any survived, or they might be allowed to remain as workers for the new owner. If the people were thrown off the land because one of their bwij had offended the iroij (collective punishment), this iroij would not take care of their needs for land. However, another iroij, hearing of this expulsion, might invite the dispossessed ones to his side and would settle them on his land, thus gaining more adherents.

Katleb does not necessarily imply punishment. If the iroij moved people off the land merely to provide land for others (not to punish transgressors), he would find land for the people whom he had dispossessed. He usually "confiscated" land from a bwij that had plenty of land.

Some katleb land had no people on it when it was "planted", due to a natural disaster, e.g., land on Ebon where all people had been killed by a typhoon about 150 years ago.

Katleb is always given to an individual, not to a bwij. The individual may call the bwij in if he wants to. He may give it to his children as informant's ancestor did 100 years ago. Katleb land may be given away to outsiders, but informants have never heard of this happening. "A man naturally wanted to take care of his kin folk or children." Only the original recipient could give it to whomever he wished, but after that it followed the regular custom through the bwij. Katleb is then inherited through the maternal side (bwij) like lāmoren land.

Mo land, Kotra (Rālik and Radak), Juluburin Ne (Radak only)--personal land of the iroij. Each iroij lablab had land called mo. He might say, pointing to an island or a parcel of land, "That is my mo." From that moment on, that particular land was forbidden to anyone but the iroij or people to whom he gave special permission. The word emo itself means forbidden or tabu.

When an individual is being treated for certain ailments, he is mo. Sexual intercourse is forbidden both to himself and the dri uno (medicine man) who is treating him during the period of treatment.

This term is derived from Jemo, an island in northern Radak, which according to tradition is the residence of Lawi Jemo, the spirit or ekjab of an iroij lablab of long ago. It was believed that Lawi Jemo, the high iroij of Jemo, dwelt in a huge kañal tree from which he sometimes emerged to walk around the island. On these occasions he is said to have appeared as a tall, strong, handsome man "because he was an iroij."

Jemo is the home of myriads of turtles and birds whose flesh and eggs have been a valuable source of protein for the people of the neighboring atolls. Stylized ritual was connected with the first food gathering expedition of the year which occurred in the summer time (rak). A fleet of canoes would sail from one of the neighboring atolls under the command of the iroij. The kakollol (or navigation aid used to fix the position) of Jemo is said to be a large flock of birds that fly out to meet the canoes about ten or fifteen miles from the island. When the birds were sighted, the helsmen would exclaim: Droror timmej or Droror mej (eyes down), as a sign of honor and respect to Lawi Jemo.

When the canoe of the expedition came in sight of Jemo Island, the women in the party had to hide under mats in the canoe; otherwise, bad luck in gathering flesh and eggs was certain to follow, so it was believed. As soon as Jemo was sighted, it was emo to use ordinary Marshallese--the laroij language was mandatory.

When the canoes were being hauled up on the beach, special roro (work chants) were used:

"Rubrub kane in madren e wulik Karoñroñ ie jitoñ,	"Break up firewood, firewood, So that we will be able to rest by the fire,
"Jitoñ rik jitoñ."	Charred wood, a little charred wood."

This was followed by:

"Rubrub jitoñ in ib jen ko karoñroñ ie jitoñ.
Jitoñ rik jitoñ."

"Break up charred firewood so that we shall gather strength at
the charred firewood."

These canoe chants were used on all of the "bird islands". They were used as late as July, 1949, on Jemo. "To make the people stronger." Several elderly informants on Ailuk and Wutrōk (nearby atolls) expressed their belief that Lawi Jemo gives them strength to haul the canoes up on the beach when they use these chants.

The iroij and all of the expedition went ashore. The iroij had to lead the first trip of the year, and he was the first person to step ashore.

Before the party commenced their search for eggs, etc., divine sanction was requested. Everyone assembled on the beach before proceeding inland and cut a leaf of coconut frond. With the iroij leading the way, they walked toward Lawi Jemo (the kañal tree) in single file, each individual carefully stepping in the footprints of the person in front of him so that only one set of footprints would appear--as if only one person had been there.

Women were required to hold mats over their heads while on the island so that they could only see the ground well enough to gather eggs, etc. They were forbidden to see Lawi Jemo. Strict silence was observed on the way to worship Lawi Jemo.

When they reached the tree, each man placed his coconut leaf over a branch of the tree and then sat down in front of the tree and waited for a breeze to come and blow the leaf off. When this occurred, the kebbwi in bwil (ritual name for the iroij on this occasion) would say: "Wurin̄" (we are lucky). If some branches also fell, the same word would be repeated.

This kind of ritual (kabun) is called katobar.

Lawi Jemo had signified his approval. Everyone then proceeded (not in single file) to a special place where marutto, a small, rare plant, grew. The iroij made medicine by pounding the marutto plant. Three yellow leaves and three green leaves were pounded together, and the extracted juice was drunk by all. This was done to prevent anal bleeding and diarrhea which might result from the unaccustomed meal of turtle and birds' eggs. Kirin leaves were made into a medicine using the same recipe if marutto extract proved ineffective. (This treatment for diarrhea is still used today throughout the Marshalls; sometimes the leaves are merely sucked.) After taking the preventative medicine, turtle eggs were gathered independently.

Before eating, everyone reassembled before the sacred tree to resume the ritual. The iroij or a senior alab whom the iroij had appointed stood before Lawi Jemo and commenced chanting:

"Jej jar um"-"we start to pray."
"Jelbo I jelbo, jelbo I lip ke kijen Lawi Jemo-"we worship, we worship, we worship--these eggs fed to Lawi Jemo."

"Ikri, ikbi ean̄ eo, Lajibwinemon"-"move it, take it, to the north for Lajibwinemon is the iroij of the north."

"N̄on rak Lorok"-"to south for Lorok is the iroij of the south."

"N̄on rear Lokbea"-"to east for Lokbea is the iroij of the east."

"N̄on kabilon̄ Lokabilon̄"-"to the west for Lokabilon̄ is the iroij of the west."

As each direction was named, four eggs were thrown out in that direction as an offering to the ekjab. The eggs were then recovered and the principal in the ritual consumed all of them. The remaining eggs were divided up and eaten by the others in the party after the leader had eaten the sacrificial eggs.

A special chant, roro, was used to obtain supernatural aid in pulling turtles ashore:

"Bwili erōk ki"- "push, rolling on shore."

"Erōk ki, erōk ki"-"rolling on shore, rolling on shore."

"Eraror wan tapeo"-"roll the food-bringing turtle. This roro is still used by some of the older northern Radak people who believe in its efficacy.

While on the "bird island", sexual intercourse was forbidden and as previously mentioned, the use of everyday Marshallese was forbidden. It was believed that supernatural punishment, mij i lāroij (sickness of the lāroij) would strike the transgressor in the form of dysentery accompanied by severe anal bleeding.

The lāroij language (stone, lā, or foundation of the iroij was mandatory at all times. This ritual language (which is still known today by some of the older people) may have been the ancestral tongue of the Marshallese, modified by centuries away from the homeland; it may have been an exclusive chiefly (iroij) language or an archaic courtesy language. At any rate, it may provide a clue in comparative linguistic studies today, e.g.:

A. ENGLISH	B. COLLOQUIAL MARSHALLESE (FORBIDDEN)	C. LAROIJ LANGUAGE (MANDATORY)
man	emman	dri kabbil
woman	kōrā	maar
boy	ladrik	laberik, naberik
pandanus	bōp	karkar
breadfruit	mā	waerar
coconut	ni	kebor
preserved pandanus	mokon	wairik
bird	bau	bebelber
octopus	kwet	werak
shark	bāko	niñniñ
sting ray	jemjo	jejanjōr
come	itok	jekabuñ
go	ilok	jekabuñlok
child	ajiri	nabdri
ship	wa	jitōñ
eggs	lip	unniñ
rat	kijrik	kilukor
sand	bok	jejakiki
fire	kijeek	mejwar
turtle	wun	wa

When the expedition was ready to depart from the island, the dri meto (navigator in charge of sailing) would order: "Jen rubrub, (let's sail!), ekwe, rube jiton kōne" (put the boat in the water). After all was ready: "Wuj jitōñ kane" (anchors aweigh!). All these orders were given in the laroij tongue which was used until the canoes were half way home. A special roro was continuously chanted by the helsman to remind people not to use ordinary Marshallese: "Aināñā - nāñā - ini - nene ene"......repeated (meaning unknown).

This ritual and special language was used on all of the "bird islands" each of which had its particular ekjab, all of whom dwell in trees with the exception of the ekjab of Bokak, Jo Bokak, a red bird (mum) who has been seen recently.

After this initial trip made by the iroij or senior person in the hierarchy, anyone else could make ensuing trips during the rest of the year. This ritual was apparently a method of conservation. Rather than allow people to swarm all over the island, possibly frightening away nesting fowl and egg-laying turtles, the iroij and senior people led the way and the food gathering proceeded in an organized, methodical fashion.

The early missionaries successfully used their prestige and persuasive powers to discourage the worship of Lawi Jemo and the other ekjab. This kabuñ (ritual) was last performed at Jemo during German times, according to a reliable informant, shortly after which the tree, Lawi Jemo, was cut down for boat timber. Today people gather turtle eggs and birds' eggs, etc., at any time of year and walk wherever they wish on Jemo. None of the tabus are observed as far as may be determined. This is true for the other bird islands as well. This religio-economic pattern clearly illustrates the close affinity of the aboriginal Marshallese religion to the ecology.

Mo or kotra land (Radak and Rālik), juloburin ne (Radak only) is land belonging to the iroij elap alone. When the iroij saw an island he liked, he had three tabu signs made and placed on the land (usually very good land), one on each end and one in the middle. These "signs" are called itkiju or jabne (no foot), i.e., no foot but the iroij'(s) may step here, and were made of a plaited coconut frond tied to the end of a stick (informant made one for illustrative purposes). The word kotra itself means the leaf (coconut frond) that makes land mo (tabu). The itkiju were placed in position one time only and were not renewed...."people know about it."

Magic (bubu) was made on the itkiju. It is believed that if any unauthorized person takes food from the island or ever sets foot on it, he will get sick and/or die. Permission to go on the land had to be obtained from the iroij. If any people had been living on the land, they were forced to leave. An uninhabited island was usually chosen, however. When the iroij died, the people could return to the land unless the new iroij continued the kotra. The iroij appointed special temporary workers who had no real workers' rights and who shared the proceeds from copra sales or the produce of the land with the iroij.

This land may be passed from father to son or it may remain within the bwij. The iroij may do what he wishes with it; it is his personal property. If the iroij should leave no close kin, the workers on the land may have it. The next iroij may not recover any of the mo land that his predecessor may have given away.

An informant's father received two pieces of land on Wotje Atoll this way. His father was iroij erik in Northern Radak. His father, Jibunemon, was paternal uncle to Murjil, the iroij lablab of Northern Radak. The informant's father had the itkiju (tabu) signs placed on the two parcels of land, and the land was inherited by the informant who is in possession of it today. Informant is a member of the noble class.

There are other parcels of kotra or mo land in Ebon, Ailiñlaplap, Majuro, and other atolls, viz:

MO LANDS OF IROIJ KABUA KABUA

Ailiñlaplap Atoll:

Islands	Wāto ko (pieces of land)
Toleōn	Batō
Edridr	Barōnekmouij
Enekanloto	Lolinmak
Tōbo	Unbar
Mattōn	Kōkomōnmōn
	Kaiuikan
	Otojome
	Kimemekan

There are no alab(s) or people with real dri jerbal rights on these lands.

Jaluit Atoll: Islands	Ebon Atoll: Islands
Arbwe	Eneor
	Mōneak

There were alab(s) and people with real dri jerbal rights on these lands before iroij Neiu took them over as mo in German times. An agreement was made whereby the proceeds from the copra produced on these lands was divided on a 50-50 share basis. This division is still in force.

In Japanese times about 1921, Lobareo, iroij elap of northern Radak, had a juloburin ne (translation: sole of foot / of iroij only may touch this land /), island in Maloelap Atoll on Taroa Island, Drinjen wāto, which he had inherited from his uncle, the previous iroij elap, Murjil. He used to take all of the money from the copra proceeds--iroij erik and iroij elap share, alab and dri jerbal share. This is the richest land on Maloelap.

The iroij may give juloburin ne land to his children or to his bwij. Royal "blood" is a prerequisite for holding this type of land. If there are no royal descendants left, the iroij elap takes the land back.

Lobareo later turned Drinjen wāto over to his son (Laibwij) who inherited all the rights except iroij elap rights which were inherited by Jajua, the next iroij elap of northern Radak. There are no permanent workers on Drinjen today and no alab. Informants have never heard of iroij juloburin ne are passed down from alab to alab; however, there are no permanent workers either, only iroij elap and alab.

Metak in Buro (pain in heart)--land given by an iroij to his cast-off wife as "her husband", i.e., a sort of alimony.* This done at the discretion of the iroij. One informant knew of a case like this at Wotje Atoll.

Metak in buro land remains in the bwij. The cast-off mate was tabu sexually to other men forever after unless the iroij told a man that he could take her sexually. This latter usually happened. A woman who had sexual intercourse without this permission was sometimes killed and the land was confiscated by the iroij. When a kajur husband was cast off by a leroij, he did not receive metak in buro land. He also was tabu sexually at all times. Women avoided him for fear of being killed for having sexual relations with him. His illicit sex partner was the only one killed.

Lowiō--land that had never been used before because of heavy underbrush. There were many of these areas in the old days. There is no lowio land today. If a kajur wanted land, he asked the iroij permission to clear a parcel of lowiō land to have rights in it. If the individual cleared the land by himself, he could leave it to his desired heir.

If his bwij helped clear the land, the bwij inherited the land. The iroij might do the clearing with his own workers and he would keep the land as his personal land. This last happened during early Japanese times, e.g., on Majuro Atoll on Ajeltak Island, Mwōnbat wāto has an iroij and temporary workers only today. Dalap, Monworwor wāto is in the same status but now occupied by an air strip. On Roñroñ Island, Eñlen wāto, iroij Lañlan cleared it himself in 1912 and changed the name from Tur (a geographic term) to its present name. Dri jerbal were put on this particular land permanently and are working it today.

Lowiō by an iroij may mean that the land may have been used by a kajur but not worked or cleared by him. The iroij cleared the land and the kajur "lost" their rights in it, i.e., a sort of punishment for not carrying out duties and obligations.

Erenteb--"something, i.e., a gift, to put your shavings (from the canoe) in." In the old days canoes were very important in the economy and in the frequent wars. In the absence of metal tools, canoe building was a difficult and time-consuming task.

When the iroij wanted a new canoe, he sent hundreds of his people out to cut a huge breadfruit tree for the hull and other trees for the supports of the outrigger, the platform, etc. Only a few men in a few lineages knew how to construct a canoe. Special knowledge of measurements was and still is handed down within the lineage.

Folded pandanus leaves were used to "blue print" the canoe. Two of these skilled men were usually in charge of the building of a huge canoe for the iroij. These men were rewarded by the iroij with gifts of mats, rope, food, etc.--never land. The other workers received nothing from the iroij but food while they were working on his canoe. One informant saw the iroij Murjil's canoe built and land was not given. Informants have never heard of land called erenteb.

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* Nets, mats, boats, clothing, etc., given to a cast-off wife by the iroij are called mweien tiriamo (these goods- things - of sorrow) or jemlok (the ending).

The man or men in charge of the canoe building was forbidden to have sexual intercourse while the canoe was being built. A dri bubu made magic to aid in building a good canoe. Bola was used before the canoe was built to find an auspiscious time. A canoe should be made when there was no danger of surprise attack that would prevent completion or allow capture of the canoe.

Enen-Kojou (land-of-make disgrace), Jou-Mij (die without land)--the iroij never took land away for adultery if just kajur were involved. However, if an iroij or leroij were involved, he or she would get land from the erring husband or wife.

If a kajur male was married to a leroij who had sexual relations with another man, the kajur might have complained to the iroij elap who would say iroij loman (iroij custom), i.e., the iroij may do anything they wish. However, if a leroij had a kajur husband (known as iroij emman both in Rālik and Radak) who committed adultery, she confiscated the land of her husband's sex partner. She did not have to consult the iroij elap about it. She possessed enough power herself. The leroij could tear her rival's vagina open as additional punishment if she wished; this was done many times according to informants.

A kajur male who had sexual intercourse with the iroij elap'(s) wife was described by a special term, lañ ebuñti (the heavens will fall upon the people / concerned /). The offending male was always speared to death by an iroij erik or bwirak-tak (lesser royalty). The offending wife could be cast off without metak in buro or killed, at the discretion of the iroij elap, but her land was not confiscated. The iroij confiscated the land of his wife's lover, kojjou (throw away). His whole bwij was thrown off the land and told: Jou mij (you will die because you have no land). The land was then called enen kojjou. Informant told of a case of this type that occured in Wutrōk Atoll in pre-German days.

A kajur male who had sexual relations with the wife of an iroij was killed and his land was given to an outsider, usually the person who executed him. His whole bwij was then evicted from the land.

Presumably this idea of collective punishment for individual transgressions of one member of the lineage was designed to prevent commoners from violating the iroij sexual rights and to accentuate the exalted position of the iroij class and everything pertaining to it. The iroij could dispose of the confiscated land as he pleased.

In the case of a kajur woman who committed adultery with the husband of a leroij, the offending woman was often taken to the ocean and drowned by all the leroij. An informant had heard of this happening in pre-European times. In one case, during Japanese times, according to an informant, a kajur male had sexual intercourse with the kajur wife of a bwirak lablab (son of an iroij lablab father and a libwirak--lesser royalty--mother). When his crime was discovered, the offended husband and all of the iroij erik and bwirak beat him into unconsciousness. The husband then forgave his wife and continued living with her.

All of the iroij were tabu sexually to kajur except on invitation of the iroij or leroij. The land of the offending mate leroij (if he was a kajur--iroij emman) could be confiscated by the leroij. If so, all of his bwij was evicted and another bwij put on the land. The evictees would move to the domain of another iroij, as in the case of land alienation of the iroij'(s) bwij. This land was passed on through the bwij of the new occupants and was then classified as kotleb.

The offenders: leroij'(s) mate and the woman involved, were either killed, beaten, or had their land confiscated, any of the three; however, they had no choice of punishment.

The leroij sometimes ordered her husband's death and sometimes her rival as well but usually had them beaten. The most usual punishment was confiscation of land. If the iroij'(s) wife was of iroij "blood", she could sleep with another man and not be subject to punishment by the iroij. He could only "get revenge" by sleeping with another woman or he might merely scold his wife. "Both iroij and leroij have the same power sc they cannot punish each other."

Conversely, if an iroij offends his (leroij) wife, she may obtain revenge by sleeping with another man. This method of "paying back", as it is called, is often practiced today by Marshallese of all classes. The leroij'(s) kajur lover could not be punished according to custom and neither could the kajur sex partner of the iroij. An iroij who had sexual relations with the wife of another iroij from the same area could not be punished.

The wife, if a commoner (lijela) could be thrown out after being beaten but her land was not confiscated. If a leroij was offended against by another leroij, the same thing applied as in the case of the two iroij. Informant laughingly told of an iroij who slept with the lijela (commoner wife of an iroij lablab). When the cuckold found out about it, he became angry but did not do anything about it. "A kajur would have been killed." This incident occured shortly before World War II. However, for example, if an iroij from the Rālik Chain came to Radak and trespassed sexually on a Radak iroij'(s) wife, war would ensue. This almost precipitated a war on Majuro more than one hundred years ago.

A bwirak (lesser iroij) who slept with a lijela would have his land confiscated but not killed; presumably because he was a member of the royal class. The land confiscated by a leroij from her rival could be given to the husband of the adultress. This was only done occasionally, and this land was passed down through the man's bwij. Land of this type was called mweien tiriamo (goods of sorrow). The land of a man who slept with the lijela (commoner wife of an iroij) was never given to his wife but was kept by the iroij.

Kaamnak--(not a land title; verb) "to put someone on the land, house, etc. Similar to kotleb land; it may be any type of land. It has often been land given by one iroij to another, e.g., Jebrik Lokotwerak, iroij lablab of one-half of Majuro Atoll during Japanese times, gave an island on Majuro Atoll to Litokwa, an iroij from Ebon Atoll in the Rālik Chain. Litokwa had promised to kaamnak land to Jebrik in return. He did not keep his promise, however, so Jebrik took the land back. This type of land is used by the iroij recipient, and after his death, it reverts to the iroij donor.

Kotra land, iroij personal land, has been given as kaamnak. Kaamnak provided the iroij with a place to stay when they visited outside their own atolls, e.g., Toemeiñ iroij of northern Radak, had land of this type in Jaluit Atoll in the Rālik chain during the Japanese times.

While the _iroij_ is away from his _kaamnak_ land, the money share from the land is given to the original _iroij_. Food is given to any of the recipient _iroij_'(s) workers who may be on the land, e.g., workers of _iroij_ Toemeiñ on his _kaamnak_ land on Jabor, Jaluit Atoll.

The usufruct rights in _kaamnak_ may be transferred to a third party, e.g., during the Japanese period, _iroij_ Jebrik Lotokwerak of Majuro gave Jable, a piece of land on Majuro, to _iroij erik_ Lañlan of Majuro as _kaamnak_. The latter had a boat made by a half-caste, Joachim de Brum, and turned this land over to him for his use in payment for the boat. He predeceased his half-caste friend, and the land reverted to the original donor.

Workers of this type of land will remain on the land, make _ekkan_, and give the copra share to the new _iroij_ when be is there. This individual will inform the original _iroij_ who will reply "keep it" (money and _ekkan_), i.e. temporary tenure is recognized by everyone involved.

CONCLUSION

The Marshallese system of land tenure has been modified in certain respects due to the acculturative influence of the bearers of western culture. Warfare has been eliminated from the pattern of culture and consequently land ownership does not fluctuate as radically as in the days of inter-clan and familial strife.

With the introduction of foreign administrative authorities and foreign concepts, the authority of the royal (_iroij_) class has progressively become weaker. However, as was stated initially, the system of inheritance and usufruct has been retained albeit modified in regard usufruct and is operating today with no overt indications of overall disintegration and with all indications of continuance. Whether further acculturation and exposure to the concepts of the American socio-economic system will cause a breakdown of the present Marshallese system of land tenure remains to be seen.

It is strongly recommended that the program of returning the former Japanese government lands to the former Marshallese owners and the payment of claims against the United States government for occupation and damage to land be expedited. It is further recommended that the land shall never be allowed to pass into non-Marshallese hands.

This is the explicit desire of the Marshallese people and was presented in a joint, unanimous resolution in the meeting of the second "Marshallese Congress" in August of this year. As such, it deserves the most serious consideration by the powers that be.

This is particularly important in view of the steady increase in population due to the superior facilities offered by the American medical program which has almost entirely eradicated venereal and other diseases that have prevented large population increase in the past.

There is no serious population pressure at the present time, but the time may come when it will become necessary to utilize every piece of land to the maximum extent as in the Southern Gilberts. This eventually should be anticipated and prepared for.

ADDENDUM

A possible future trend was seen only this week in the request of an alab on Jarej Island, Majuro Atoll (adjacent to the Administrative Center) to collect cash rentals from various individuals whose bwij lands are in other areas and who have built retail stores and bakeries on this individual's bwij land.

GLOSSARY

A brief resume of terminology used in connection with land rights follows:

Ailiñ.......................... atoll

Ajri.......................... literally "child"; as used in reference to a person living and working on his father's land.

Alab.......................... the senior member of the bwij; the head man or woman of a wāto or group of wāto(s).

Bolā.......................... divination by means of stones (counted out in series).

Burij.......................... land (noun).

Bwij.......................... literally "navel"; the extended family group or lineage; used to refer to the maternal lineage primarily but is also used to refer to the paternal lineage, e.g., "that is my father's bwij land." Bwij is sometimes used as a synonym for jowi (clan).

Bwij eo elot.................... means that the bwij has become extinct; all the lineal descendants of the founder of the bwij have died.

Bwirak.......................... title of lesser royalty; libwirak--feminine.

Dri jerbal...................... literally "work people"; everyone who works on the land with the exception of the alab. This is a comparatively new term that came into usage with the introduction of a cash economy with copra as its base. The people who have the indisputable rights in a particular piece of land are those who might possibly become alab through their matrilineal lineage. The ajri or children of the male alab form another category and yet another consists of those individuals who are real outsiders, being neither paternal nor maternal relatives but who have been allowed to work on the land.

Ekkan.......................... tribute paid to the iroij: food, mats, etc.

Emo.............................. forbidden, tabu.

Ene.............................. island.

Eonene........................... the main island.

Iroij emman...................... commoner husband of a leroij.

Iroij elap or iroij lablab...... king or paramount chief; the alab of the senior royal bwij; leroij--queen or chiefess.

Iroij erik....................... literally "little chief"; secondary chief; used in the Radak chain only.

Jikin............................ place (noun); referring to a piece of land.

Jikin kwellok.................... place of assembly; village

Jikin jemeir..................... land of paternal relatives; 3rd person plural.

Jikin jineir..................... land of maternal relatives; 3rd person plural.

Jowi............................. clan, matrilineal and strictly exogamous with one exception: jirikrik, "because there are so many jirikrik".

Kajur............................ commoner.

Kōkajiriri....................... adopted child; literally: "to rock and fondle in one's arms", i.e., to "look out" for a child.

Lijela........................... commoner wife of an iroij.

Mañoren.......................... maternal nephews or nieces.

Mañoren lōboren.................. eldest female mañoren (the most important because her children will eventually become alab).

Nukin............................ relatives, paternal and maternal.

Radak............................ eastern chain of atolls and islands: Bokak, Bikar, Wutrōk, Ailuk, Wotje, Erikub, Maloelap, Aur, Majuro, Arno, Mille, Tōke, Likiep, Narikrik, Jemo Island, and Mejij Island.

Rālik..........................	western chain of atolls and islands: Roñlap, Wotto, Lae, Ujae, Kuajlen (Kwajalein), Ellip Island, Namu, Ailiñlaplap, Jaluit, Namrik, Ebon, Kili Island, Ujilañ, Ailiñinae, Roñrik, Enewetak, Bikini, and Jabwot Island.
Rārōk..........................	islands (ene ko) or wāto(s) (wāto ko) used for making copra but not regularly inhabited; also used to describe waste land, full of coral boulders and sand left by a typhoon; area of poor soil. Usually the S. or S.E. portion of an atoll. Called aeañ when on N. or N.W. and liklal when in the western portion.
Rukorea (Rālik), Muleba (Radak).	maternal uncle.

Dialectical differences in terminology (Rālik and Radak chains) are noted where existent in this paper.

Diacritical marks: ā--as in back, sack; ō--approximately as "u" in murder; ñ--"ng" as in sing, king, etc.

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APPENDIX

MODIFICATION OF THE LAND TENURE SYSTEM ON UJILAÑ BY THE DISPLACED ENEWETAK PEOPLE

When the former inhabitants of Enewetak were re-located on Ujilañ, the naval authorities allocated one-half of the atoll to each of the iroij lablab Johanes and Abream, following the pattern that prevailed on Enewetak.

In 1949 each iroij then divided the land allocated to him, among his people. Each individual (from the youngest child to the oldest adult) received a plot of land some of which support less than ten coconut trees. The alab does not receive a share of the dri jerbal copra nor (as previously stated) does the iroij.

As may be seen, this new pattern of allocating individual land holdings is a drastic modification of the traditional Marshallese land tenure system. Whether this change was brought about by acculturation from the neighboring Ponape District within which Ujilañ was incorporated administratively during the Japanese period, or whether it was a result of suggestions by American administrative authorities is not clear at the present time, due to lack of detailed information. Further investigation is needed here.

Nos. 12, 13, 14 December 15, 1952

ATOLL RESEARCH BULLETIN

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by PRESTON E. CLOUD, JR.

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14. Description of Kayangel Atoll, Palau Islands

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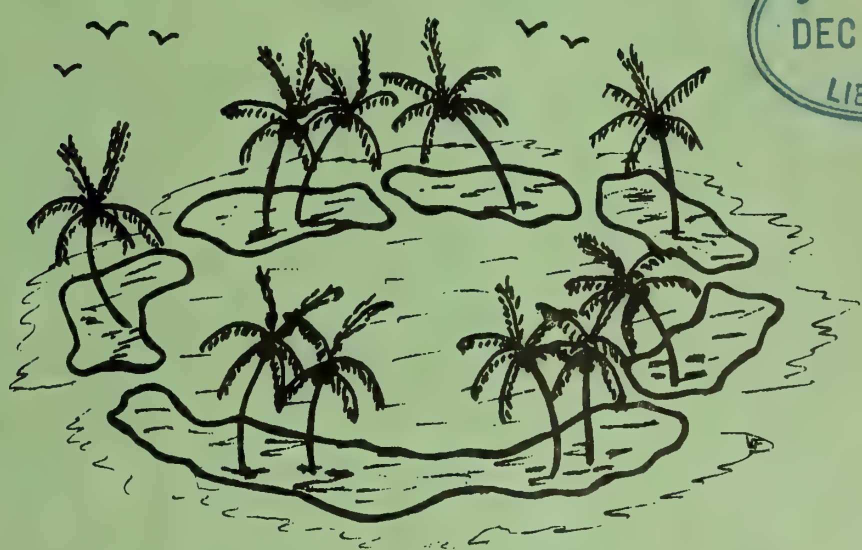

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ACKNOWLEDGEMENT

It is a pleasure to commend the far-sighted policy of the Office of Naval Research, with its emphasis on basic research, as a result of which a grant has made possible the continuation of the Coral Atoll Program of the Pacific Science Board.

It is of interest to note, historically, that much of the fundamental information on atolls of the Pacific was gathered by the U. S. Navy's South Pacific Exploring Expedition, over one hundred years ago, under the command of Captain Charles Wilkes. The continuing nature of such scientific interest by the Navy is shown by the support for the Pacific Science Board's research programs, CIMA, SIM, and ICCP, during the past five years. The Coral Atoll Program is a part of SIM.

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Correspondence concerning the Atoll Research Bulletin should be addressed to the above

c/o Pacific Science Board
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2101 Constitution Avenue, N.W.
Washington 25, D.C., U.S.A.

NOTICE

The editors of the Atoll Research Bulletin are engaged in compiling bibliographies covering several phases of the science of coral atolls as well as the vegetation of high islands. They will greatly appreciate having any papers mentioning atolls or low coral islands brought to their attention. If readers of the Bulletin care to send in copies of their own papers, this will make it more certain that they will be included in the appropriate bibliographies, and the papers will be available in the Pacific Vegetation Project files for use of those interested. It may be possible, from time to time, to issue reviews of papers that are sent in, especially if they have a direct bearing on the work of the Atoll Research Program, or of the Pacific Vegetation Project.

Such papers should be addressed to:

The Pacific Vegetation Project
c/o National Research Council
2101 Constitution Avenue, N. W.
Washington 25, D. C., U. S. A.

ERRATA

In maps accompanying several of the earlier numbers of the Atoll Research Bulletin, especially nos. 5, 9, and 10, ratio scales, e.g. 1: 10,000, 1: 7500, were inadvertently left in the maps when they were reduced for publication. Reduction, of course, makes these inaccurate. They should be deleted or disregarded.

On the title page of Bulletin no. 10 should be added after the author's name the following: (assisted by John Tobin and Gerald Wade).

ATOLL RESEARCH BULLETIN

No. 12

Preliminary Report on Geology and Marine Environments of Onotoa Atoll, Gilbert Islands

by Preston E. Cloud, Jr.

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Preliminary Report on the Geology and Marine Environments of Onotoa Atoll, Gilbert Islands

SCIENTIFIC INVESTIGATIONS IN MICRONESIA

Pacific Science Board

National Research Council

Preston E. Cloud, Jr.
U. S. Geological Survey
Washington, D. C.
June 1952

ACKNOWLEDGMENTS

This report presents preliminary results of geological field work done in 1951 under the Atoll Project of the National Research Council's Pacific Science Board. The project is supported by funds granted to the National Academy of Sciences by the Office of Naval Research, and the field work was carried out with the active assistance of the U. S. Navy Department, Coast Guard, and Army. Special thanks are due for help received from Mr. Harold Coolidge, Miss Ernestine Akers, and Mrs. Lenore Smith, of the Pacific Science Board, and from Lt. M. E. Katona and Ens. Lee Nehrt, of the U. S. Coast Guard cutter "Nettle." My associates in the field were Dr. E. T. Moul, Dr. W. H. Goodenough, Dr. A. H. Banner, Mr. D. E. Strasburg, and Mr. John Randall.

The field work of the Onotoa Party being in the Gilbert and Ellice Islands Colony, we were the guests of the British Government, then represented by Acting Resident Commissioner R. J. Keegan, who took a most helpful personal interest in our work. Special courtesies and favors were also received from Mr. B. C. Cartland, Mr. Stanley Silver, and Mr. Alan Hart, of the Tarawa Government staff.

The then Colony Lands Commissioner and Administrative Officer on Onotoa, Mr. Richard Turpin, and his wife befriended and helped the entire field party in every conceivable way--to have them as "guardians" was a great help in carrying out our work among a people whose language and ways were remote from ours.

Finally, I must thank the people of Onotoa themselves, who welcomed us to their island and helped us as much as they could.

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PRELIMINARY REPORT ON THE GEOLOGY AND MARINE ENVIRONMENTS OF ONOTOA ATOLL, GILBERT ISLANDS 1/

By Preston E. Cloud, Jr. 2/

1/ Publication authorized by the Director, U. S. Geological Survey.

2/ Geologist, U. S. Geological Survey.

ABSTRACT

Onotoa is a "dry" atoll just south of the equator and west of the international date line. Its yearly rainfall averages only about 40 inches, droughts occur periodically, and ground cover vegetation is sparse. Island deposits are almost exclusively unconsolidated calcium carbonate gravel and sand, the gravel mainly toward the sea and the sand mainly lagoonward. Within this permeable material and the permeable reef-rock beneath, ground water floats in hydrostatic balance with sea water below. Toward the center of islands more than about 1000 feet wide this water is generally potable. In narrower parts of islands, however, it becomes brackish at times of drought, resulting in the death of breadfruit, taro, and even coconut trees. Soils are simply the calcium carbonate sediments, with a humus layer not exceeding about 10 inches and an average pH of about 8.1.

The shape of the lagoon bottom is derived from echo sounding and direct observation. It comprises three shallow basins (maximum depth 8 fathoms) that are separated from one another and from the sea beyond by still shallower water, the whole with numerous small patch reefs that rise to or near the surface. The near-surface framework of the Onotoa reefs consists primarily

of the blue alcyonarian *Heliopora*, a genus that is not extensively developed there among now living corals. Fish are shown to be important in the production of lagoonal sediments.

The sediments, soils, and surface waters of the island areas of Onotoa, and the ecologic zones and deposits of its shallow marine waters, are here provisionally described and classified. Preliminary identifications of coral collections indicate them to include about 26 genera and 50 to 60 species.

Limited observations on the chemistry and movement of some of the shallow marine waters show a diurnal variation in pH and an out-flowing gravity current across the windward reef flat and upper benched reef slope. During the day pH rises and precipitation of $CaCO_3$ probably occurs in very shallow waters. At night pH falls, favoring solution of $CaCO_3$ in intertidal environments. Dominance of solution effects in the shore zone is believed to result from constant flushing of precipitated products. The out-flowing gravity current is believed an important factor in origin of offshore grooves and surge channels, through abrasion by debris in transit seaward at times of bench truncation.

It is argued that blue-green sediment-binding and lime-precipitating algae are important in formation of beachrock, presumably both through bonding of successive surface layers and through interstitial precipitation of $CaCO_3$.

Atoll islands are built on sufficiently wide reef foundations at or near the surface of the sea at a distance from the reef front determined by local force of storm waves and to a width determined by time and supply of sediment. First a gravel ridge or rampart is erected by storm waves on the reef flat. On the lagoon side of this gravel rampart the sandy portions of the islands

grow by longshore drift of reef flat debris and by wind action. Erosion occurs mainly at times of storm by breaching or complete removal of islands.

Onotoa provides additional evidence in support of the now well-documented 6-foot eustatic fall of sea level that began probably more than 4000 and less than 7000 years ago. The evidence consists of elevated Heliopora flats and elevated cobble stripes such as are known to form only on the reef flat. The superficial appearance of modern reef surfaces in the tropical belt is attributed primarily to whether they were within 6 feet of sea level when this recession began.

INTRODUCTION

This report presents some of the preliminary results of an integrated program of field studies on the terrestrial and marine botany and zoology, geology, and anthropology of Onotoa (Ō nō' tō a), a "dry" atoll in the southern Gilbert Islands (the Kingsmill Group of early records). These studies were made by a field team of the Pacific Science Board during late June, July, and August of 1951.

The Gilbert Islands (fig. 1) straddle the equator just west of the international date line, and the position of the anchorage at the west side and toward the north end of Onotoa was determined by Ens. Lee Nehrt of USCGC "Nettle" as 1°47'33" S., 175°29'30" E. (U. S. Hydrographic Office, 1950, p. 51, states "northwestern end in 1°46' S., 175°30' S."). Onotoa is the most southerly atoll of the group, though two "reef islands" (Tamana and Arorae) lie still farther south.

Operations were carried out from a temporary base camp adjacent to the Government Station on the more northerly of the two main islands of Onotoa (fig. 2). Materials and equipment for camp and technical operations were assembled at Kwajalein and transported to Onotoa by the U. S. Coast Guard Cutter "Nettle," under command of Lt. M. E. Katona.

All botanical names used in this report were supplied by Dr. E. T. Moul and represent either his provisional field identifications or my extensions of them. All titrations for salinity factors were made and computed in the field by Mr. D. E. Strasburg, my assistant in the geologic field studies. Preliminary identifications of corals were provided by Dr. J. W. Wells, of arthropods by Dr. F. A. Chace, and of mollusks by Dr. H. A. Rehder and Mr. R. T. Abbott.

The general setting of Onotoa with reference to currents, winds, and geography is shown in figure 1. This atoll lies between the west-flowing south equatorial current and the east-flowing equatorial countercurrent. A local north-flowing current is suggested by the fact that during our stay there a marked swell from the south produced strong surf on exposed lee reefs that face the south (fig. 2). At the same time surf was weak along the stretch of lee reef north from the anchorage around the north end of the atoll to the large northern island (fig. 2).

According to the map on which figure 1 was based, Onotoa lies at about the northern limit of the southeast trade winds. During late June, July, and August of 1951 the wind blew almost steadily from a little south of east to nearly due east, with the exception of recurrent winds from the west on June 24 and 25 and of occasional squalls from the southeast to south-southeast. On one occasion winds of gale or near-gale velocity blew intermittently from the east and southeast for the better part of a day. The British Colonial Office (1950, p. 39) has reported that "For most of the year there is a steady easterly trade wind, but from October to March...occasional west and northwest gales occur. The wind in these gales does not reach hurricane force." An exception to the rule is found in the record of a hurricane at Butaritari in the northern Gilberts, variously dated as December 1927 and January 1928 (Sachet, in Pac. Sci. Bd ., 1951, pp. 8-9).

The climate of Onotoa is warm and even. For the Colony as a whole, the British Colonial Office (1950, p. 39) reports a temperature range of 80° to 90° by day, with a minimum of 70° at night. Our party maintained no systematic

records of air temperature, but I observed a midday high of 87° to 90° F. between noon and 3 p.m. on several occasions in July and August, and on one occasion the midday temperature stood at a low of 76° F. following a period of gale and near-gale velocity winds. At night the temperature fell into the 70's, to as low as 72° between midnight and 5 a.m.

A summary of rainfall data for the Colony as a whole is given by the British Colonial Office (1950, p. 39) as follows:

> "Rainfall varies considerably, not only between the islands, but also from year to year. In an average year the annual rainfall ranges from 40 inches in the vicinity of the equator to 100 inches in the extreme northern Gilberts, with something around 120 inches in the Ellice Islands. In the Phoenix Islands between 40 and 60 inches is a good year's figure, while the Line Islands' rainfall varies from 30 odd inches at Christmas Island to 150 or more at Washington Island. Ocean Island, the central and southern Gilberts, the Phoenix Islands and Christmas Island are subject to severe droughts lasting many months, when the annual rainfall may fall to less than 20 inches. These droughts are said to have a rough cycle of about seven years. In normal years the wettest months are December to February and the driest from August to October."

About 40 inches may be taken as a round figure for the average annual rainfall of Onotoa. Rainfall records locally available were kept at the Government Station on the northern main island by Gilbertese technicians for 1938 and from January 1944 through August 1951 (table 1). These show an average of 44.2 inches per year. The yearly average for the period 1924 to 1930 was 38 inches, according to E. H. Bryan, Jr. (Pac. Sci. Bd., 1951, p. 2). Available records from 1924 through 1934 led Miss Sachet (Pac. Sci. Bd., 1951, p. 16) to an annual estimate of 34.41 inches. The records of table 1 show 1946 as the wettest year, with 85.1 inches, and 1950 as the driest, with only 6.6 inches.

January averages the wettest month, with 8.6 inches, and October the driest, with 1.3 inches. The wettest month on record was January 1949, with 25.4 inches, and zero rainfall has been recorded for every month in the year except July, August, September, and November. In 1950 no rain at all was recorded from January 1 through June.

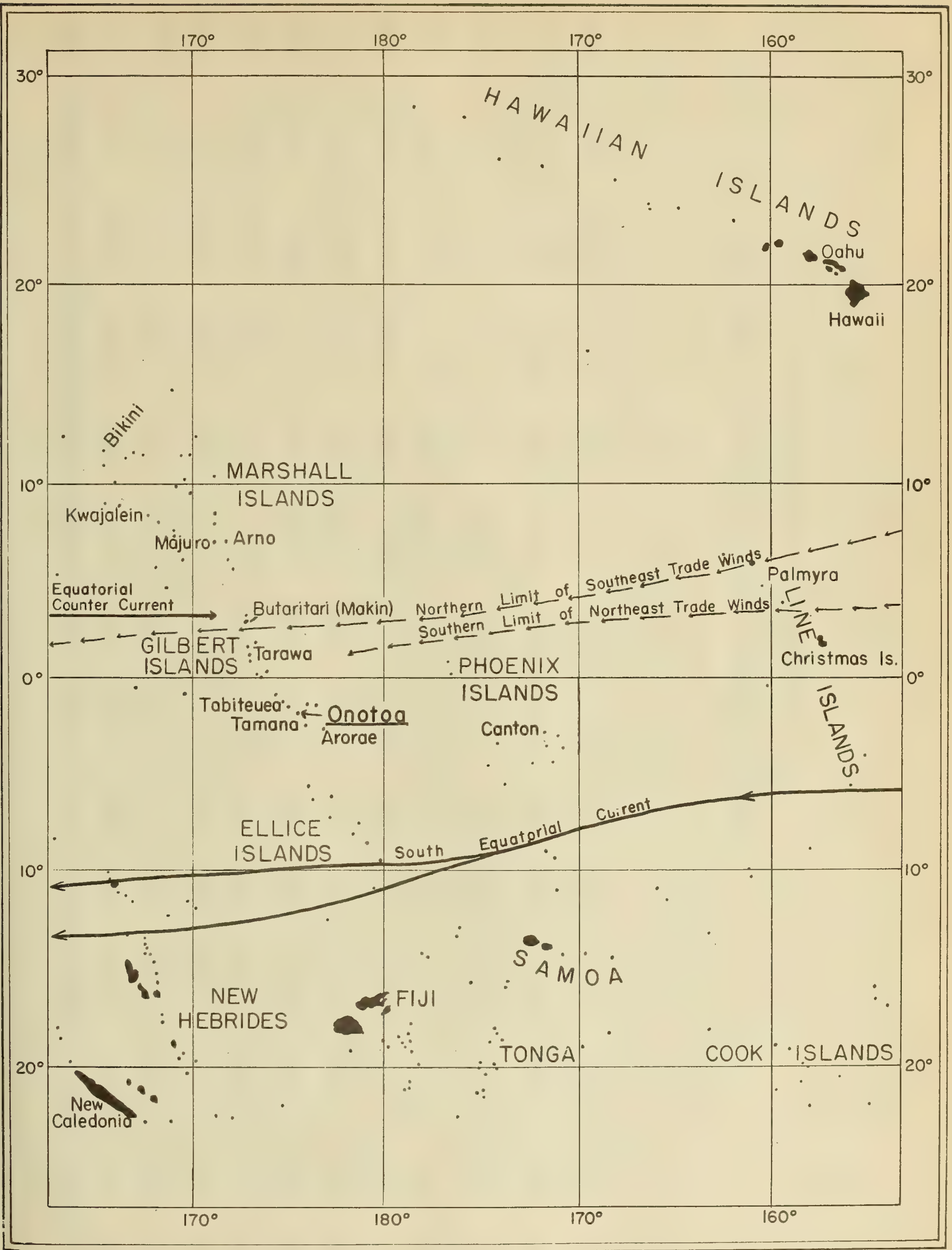

FIGURE I. INDEX MAP, SHOWING LOCATION OF ONOTOA
(From National Geographic Society, map of "Pacific Ocean", Sept. 1943.)

	January	February	March	April	May	June	July	August	September	October	November	December	Total Year
1938	1.18	0.04	1.54	0.13	1.45	1.77	1.87	1.82	3.44	2.81	2.27	0.75	19.1
1944	12.40	0.19	2.73	2.75	0	4.58	3.40	3.09	2.31	0.76	6.10	0	38.3
1945	1.20	0	0.29	1.05	2.88	8.61	5.61	2.59	1.08	0.58	3.50	0	27.4
1946	2.46	2.78	3.93	9.68	6.94	12.53	8.33	8.21	5.94	3.61	1.92	18.76	85.1
1947	16.06	0.23	0.53	0.56	1.22	3.32	0.49	1.26	0.17	0	3.21	3.46	30.5
1948	11.40	20.51	8.62	13.72	7.97	5.42	2.32	1.53	0.95	1.43	3.34	22.29	99.5
1949	25.37	4.85	3.90	0.89	3.76	1.50	2.34	0.98	0.97	0.91	0.23	0.24	45.9
1950	0	0	0	0	0	0	1.80	2.76	0.80	0	0.43	0.77	6.6
1951	7.62	0.50	2.74	2.47	11.99	7.85	12.47	9.35	?	?	?	?	--
Total	77.69	29.10	24.28	31.25	36.21	45.58	38.63	31.59	15.66	10.10	21.00	46.27	352.4
Avg.	8.63	3.23	2.69	3.47	4.01	5.51	4.29	3.51	1.83	1.26	2.62	5.78	44.2

Table 1. Rainfall at Government Station, Onotoa Atoll

(courtesy British Colonial Govt.)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total Year
1946	?	?	?	?.	?	?	13.68	4.22	1.56	5.19	9.28	11.24	---
1947	18.49	3.09	4.33	3.72	9.97	8.19	3.21	2.26	0.81	2.47	4.77	10.83	72.14
1948	21.21	9.35	18.02	15.97	8.43	8.99	6.04	4.69	1.11	1.28	5.31	15.09	115.49
1949	30.04	8.07	11.05	15.96	2.77	2.79	14.74	0.13	2.28	0.36	1.56	1.27	91.02
1950	0.52	0.17	0.15	0.67	0.49	0.49	0.59	3.00	1.20	1.80	2.72	3.73	15.35
1951	9.00	2.24	2.37	8.96	11.51	11.51	10.23	?	?	?	?	?	--
Total	79.26	22.92	35.92	45.28	29.06	31.97	48.49	14.30	6.96	11.10	23.64	42.16	294.00
Avg.	15.85	4.58	7.18	9.06	5.81	6.39	8.08	2.86	1.39	2.22	4.73	8.43	73.50

Table 2. Rainfall at Betio Island, Tarawa Atoll

(courtesy British Colonial Govt.)

In terms of the many characteristically "wet" atolls of the Pacific, where yearly rainfall commonly averages 100 inches or more, Onotoa is truly a "dry" atoll. This, of course, is immediately evident from its sparse ground-cover vegetation. Its climate over a period of years shows no clear division into rainy season and dry season--merely a slight tendency to be drier during September through November and less dry during December, January, and June. This, in turn, suggests only a slight correlation of relative dryness with the season of prevailing easterly trade winds (about late June through November) and of relative "wetness" with the season of more variable winds (about December through early June). Even in the Gilberts Onotoa is relatively dry as compared with an atoll like Tarawa (table 2), which averaged 73.5 inches of rainfall per year from 1947 through 1950.

Statistics for the drought year 1950 at Onotoa and Tarawa are given in tables 1 and 2. At such times the rainfall is insufficient to maintain a fresh-water head, permitting invasion of salt or brackish water through the pervious island sediments and rock foundation. The ground water in the narrower parts of the islands is soon contaminated, with resultant death of breadfruit and eventual death even of coconut trees. Taro too may be adversely affected, although it is ordinarily planted far enough inland to escape the worst effects, and at least one variety found on Onotoa survives in slightly brackish water. To judge from field observations, the only reasonably safe answer to the loss of plant products by drought is to avoid planting breadfruit, coconut, or taro on parts of islands less than 800 feet wide (or, better, 1000 feet wide) and to plant breadfruit not nearer than about 200 feet from standing salt water in any direction.

The effects of drought on ordinary water supply are judged to be less serious than on vegetation. The fluid drunk in largest volume by natives is

green coconut milk, which is self purified. Water for cooking and incidental drinking can be slightly brackish without deleterious effects, and the fresh-water lens of a permeable island area $\frac{1}{4}$ mile or more wide should survive the moderate draft of an endemic island population even during drought periods, especially if washing water is drawn from sources already gone brackish.

The importance that one attaches to the name of a place depends on his perspective. The Gilbertese, living in his atoll universe and dependent on the sea for a living, attaches great significance to the passes in the reef through which he can safely sail his outrigger canoe, to the reefs on which he might wreck it, and to the parcels of ground on which he and his neighbors live and over which they quarrel. He is not interested in names for a whole island or islet, except as it happens that the smaller islets are commonly single parcels of real estate. He does not go to the north or south end of some named island or islet, he goes to some particular named property or to the home of some fellow Onotoan at the village of Temao (Tĕ-mä́-ō) or Tekawa (Tē-kä́-wå).

On figure 2 only a few of the more important place names are given. The names of the seven villages are capitalized. Several islets that coincide with property divisions are indicated by the names of those property divisions in lower case lettering. The few reef names used are indicated by the Gilbertese word for reef, rakai (rá-kī); except for Aon te Baba (äń-tĕ-bä-bå) and Aon te Rabata (rå-bä́-tå), to the north and south respectively of the main passage. Aon means on, and te is the definite article, the two together being used in a sort of vernacular sense in combination with the designating name, as we speak of "Smith's place" or "at Joe Webbs" in English. With continued usage such designations take on a sort of formality, and even come to be run together as a single word (like Pittsburg, Beekmantown, Yorkshire, and Aonteuma (äń-tĕ́-ŭ-ma)).

There is nothing to call the two main islands of Onotoa except the north island and the south island unless names are concocted, and nothing would be

gained by this - the Gilbertese would be bewildered, and Onotoa is already a small enough named subdivision in world geography. The headquarters of the Colonial administrative office on Onotoa is at a place called Buraitan (Bur-i-tân). However, as frequent reference is made to this place and our campsite at its south edge, and as the land areas on the larger islands are not named, it seems easier for the reader to call this place Government Station. For the same reason it seems better that the anchorage be called just that, rather than Komotu (literally anchorage, in Gilbertese).

The authenticity of the names used, as well as the dozens of others not shown on the preliminary map, was checked in the field at every opportunity and finally reviewed on the last day of our sojourn by a group of six "old men" or Unimani (community elders respected for their knowledge) representing five of the seven villages. Because of the close village life and regular habits and travels of the people a man from one part of Onotoa may be quite unfamiliar with names for natural features of other parts of the atoll (the reefs and passes especially), but the concordant judgement of the committee of six would certainly be accepted as final by most Onotoans.

Pronunciation is another problem. To reduce it to its simplest immediately pertinent and practical terms keep in mind that the sound indicated by b is almost that of the letter p, the combination ma sounds like mwa with an almost imperceptible w, the terminal ti is pronounced like an s, and other terminal i's are silent. Rules for syllabification and emphasis are more complicated, but pronunciation is indicated for important words upon their first use in this report.

GENERAL FEATURES OF THE LAGOON

Reference to figure 2 will show the general shape of the Onotoa lagoon bottom as contoured from 21 echo sounding traverses, a few spot soundings, and submarine details visible on air photographs. This chart may not be relied upon in detail for navigation, however. In general, the underwater contour lines refer only to the general depth of bottom between patch reefs. Although a few large patch reefs are individually contoured, no indication is given of the positions of the numerous small reefs that reach to or near the surface over a large part of the lagoon.

Unless one has learned some particular channel or is completely familiar with the lagoon, he should not attempt to negotiate its waters in any kind of boat (including canoes) without keeping a very sharp lookout for reefs and shoals, and he should avoid travel on the lagoon at night. For ordinary ships' boats the only reasonably clear shore approaches are within the segment defined by lines of fathometer traverses A and 8 to the jetty at Government Station and about along or a little south of the line of traverse G to the Maneaba (Mwȧ́-ē-ȧ́-bȧ) at Aiaki (ī́-ăk). A course along traverse G would need to evade linear patch reefs between 4000 and 5000 feet offshore, and there is no anchorage for ships off the outer reef here. There are no navigation lights or buoys anywhere, and the only good sighting points are the ends of islands, the white stone monument on Aonteuma, and the churches and large community meeting houses, or Maneabas, shown on figure 2.

The only suitable anchorage for larger vessels at Onotoa is on the leeward shelf outside the gap in the outer reef opposite Government Station. This is a well-protected anchorage except at the rare times of westerly winds. It has a good holding bottom and adequate swinging room. It is reported

(U. S. Hydrographic Office, 1940) that small ships may anchor near "Taburari" (Tȧb′-ü-ȧr′-ôr-ī) at the south end of the island. However, the only possible anchorage at this place is a very narrow shelf right against the reef and generally swept by a rolling swell from the south--an undesirable anchorage except at times of dead calm. To my knowledge, no vessel of any size has ever entered the Onotoa lagoon. It would be possible, however, by careful manipulation, to work a vessel of less than 9-foot draft into the lagoon and anchor it there, and it might be worth doing if one were to be there beyond a few days. It would also be possible to clear channel and anchorage in the lagoon for regular use by vessels up to 9-foot draft.

The intended reference datum for the depth contours in figure 2 is mean low low tide. This datum can be only roughly approximated, as the U. S. Coast and Geodetic Survey "Tide Tables" for 1951 give no correction factors for Onotoa tides. They do give records for several other Gilbert atolls, and I have arbitrarily assumed the same corrections as for Nonouti (nō-nüch), with Kwajalein as reference point. This gives 6.2 feet as the spring range of tide and 4.4 feet as the mean range of tide. No effort was made to make a precise check on these data, but the assumed ranges and times seemed about right in the field, with considerable local lag in enclosed tide flats and tidal inlets.

Depth traverses were made with Navy Model NK-7 portable echo sounding equipment, which consists of a magnetostrictively actuated transmitter-receiver unit in an outboard wooden fish and a recorder unit that produces a continuous graphic record on a strip of sensitized chart paper. This fathometer was carried in a 20-foot flat-bottomed dinghy driven by a 7-horsepower outboard motor. It was operated by two parallel-connected 6-volt automobile batteries which proved of inadequate capacity to maintain the sensitivity required to operate at depths below 200 feet for more than very short periods.

E.

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XPLANATION

Limesand

Limegravel

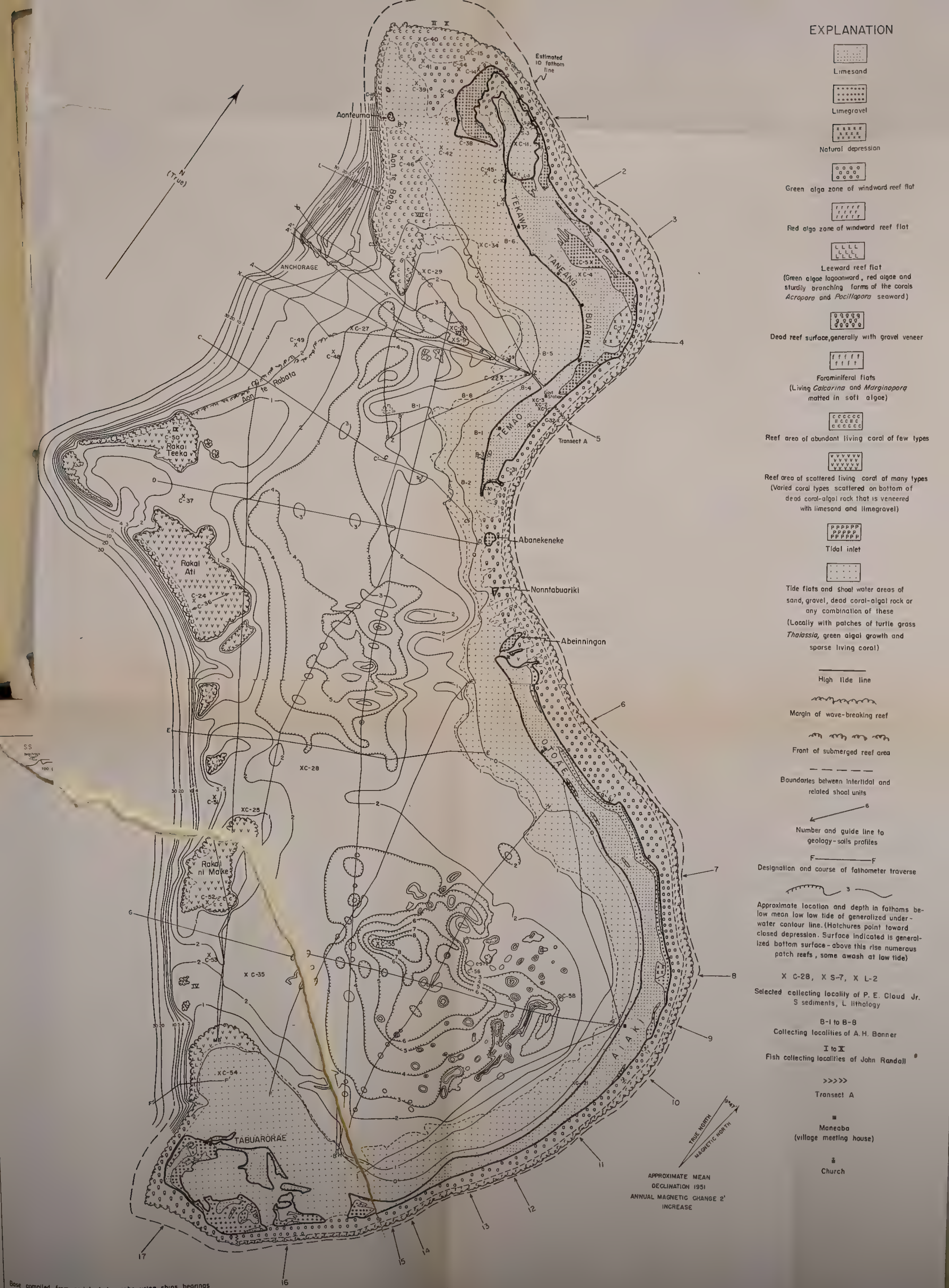

FIGURE 2. GENERALIZED GEOLOGY AND MARINE ENVIRONMENTS OF ONOTOA ATOLL
GILBERT ISLANDS
By Preston E. Cloud Jr.

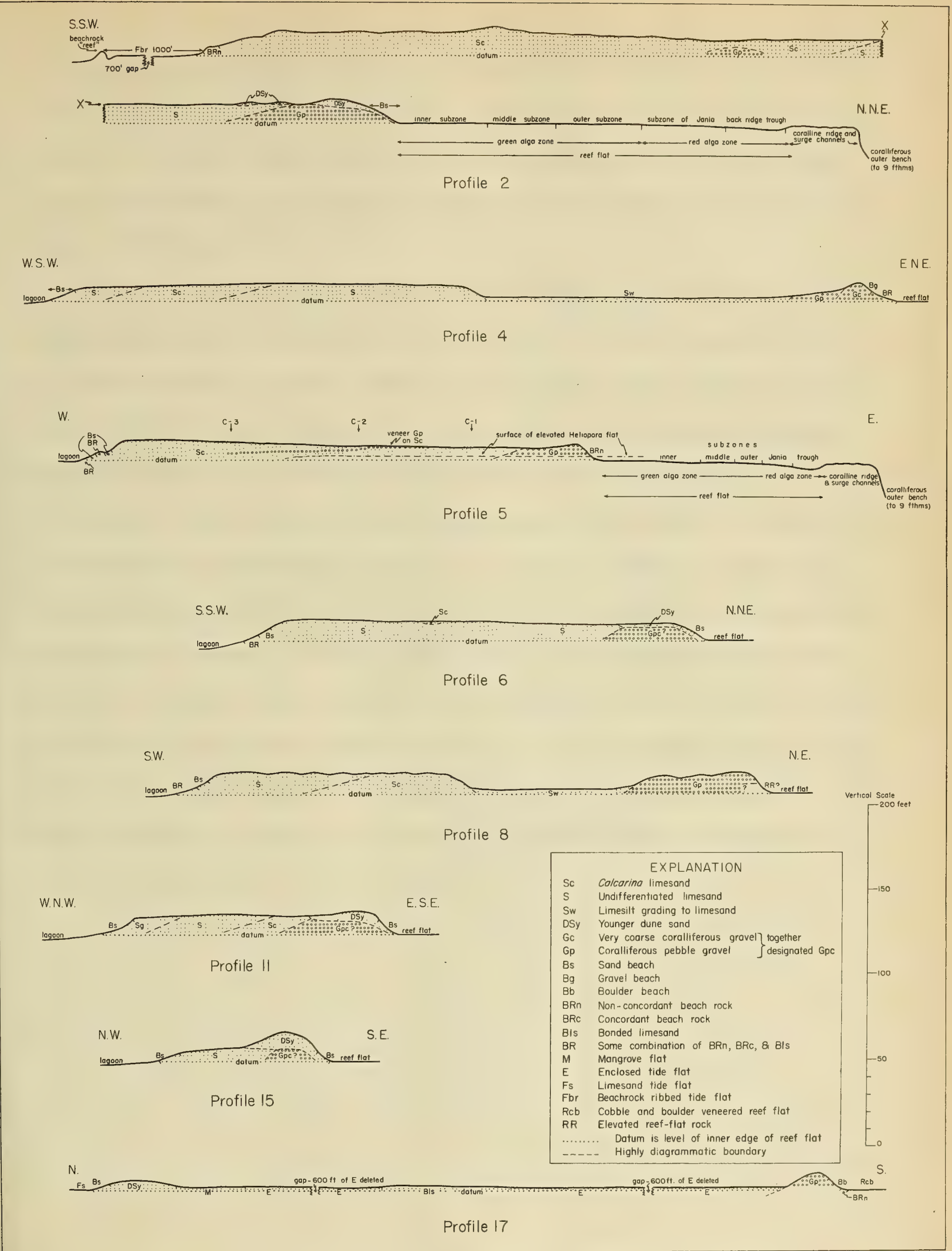

FIGURE 3. ISLAND PROFILES, ONOTOA ATOLL

(Vertical exaggeration 5x. Minor and man made irregularities eliminated or generalized. Location shown by number on Figure 2)

Horizontal Scale

0 100 200 300 400 500 1000 feet

A clear record was produced, however, from depths of 200 feet on the outer reef slope into very shoal waters, and, after approximate correction for tide conditions and depth below surface of the transmitter-receiver fish, this record was accepted as the basis for contouring the bottom of the lagoon and upper reef slopes.

Figure 2 shows that the lagoon is very shallow, its maximum depth of 8 fathoms being based on two hand-lead soundings at and near locality C-55. The general bottom topography (excluding the numerous small patch reefs) consists of three shallow basins. The south basin is the largest and deepest, generally deeper than 6 fathoms in its central part and attaining a maximum of 8 fathoms. The central and north basins connect and might be thought of as a single long narrow basin generally exceeding 3 fathoms in depth and attenuated in the middle. The central basin proper exceeds 4 fathoms over a fairly large area and 5 fathoms locally. The north basin has only a small area that is deeper than 4 fathoms. All three basins are separated from one another and from the outer deeps by shelves of 2- to 3-fathom depth. In the passes through the outer reef the depth nowhere much exceeds 2 fathoms. Between the many patch reefs the lagoon bottom is everywhere floored with calcium carbonate sand, silt, or gravel.

Systematic studies of the plants and animals, and chemical and mechanical analyses of the sediments and rocks of Onotoa are still in progress. Until these are completed it seems preferable here merely to mention some of the more general or interesting facts and inferences about the principal habitats and deposits of this atoll. As a possible aid to those engaged in comparative studies of atolls, brief descriptions of ecologic and sedimentary units as recognized in the field are given in Appendix B.

Islands

The land area of Onotoa is given by Leonard Mason (In Freeman et al., 1951, p. 274) as 5.2 square miles and the lagoon area as 21 square miles. The land surface is mostly unconsolidated sand and gravel (fig. 2). Solid rock is rare. The sand, gravel, and rock are entirely of calcium carbonate (except for the generally small magnesium content of some algae and shells), a little humus, man-carried debris, and minor amounts of siliceous pumice that has been washed up from distant volcanic eruptions. As they are thus all limesands, limegravels, and limestones, the prefix "lime" (used by geologists to signify $CaCO_3$) should be understood where not actually used in the following pages.

If Onotoa were part of an extensive land area, probably no geologist would make finer distinction of its sediments than that between sand and gravel. Because its land area is small, however, and because details of sediment distribution may be helpful in understanding processes, effort was made to distinguish, and in a general way to map as many different kinds of sediments as could be recognized. For soil classification and vegetation relationships it seems also likely that only a few main types of soils should be recognized:

(1) loose limesands with a well-marked humus layer; (2) loose limesands without a humus layer (younger dune sands); (3) tight-packed, low-lying, generally damp and brackish limesilts and very fine-grained limesands; (4) indurated, phosphatized (?) limesands (old dunes); (5) coarse gravels; and (6) pebble gravels. The properties of the finer pebble gravels at places approach those of the loose limesands, and impinging units ordinarily show gradational relationships.

Soil profiles were run at five localities on loose limesands, at a sixth locality on pebble gravels, and at a seventh on limesilts; and depth of humus was observed at many localities. Tests with a standard Truogg soil testing kit gave a pH of 8.1 for the surface layer of all profiles except that on the damp limesilt, and this had a pH of 8.0. There seemed a slight tendency for pH to increase a little with depth, to as high as 8.3 well below the thin soil layer in fresh parent limesands, but no reading above pH 8.3 was made at any depth. It is difficult, however, to be sure of Truogg index colors as closely as the foregoing suggests, and the difference between 8.0 and 8.3 might be imaginary. Maximum recorded thickness of a well-defined humus layer was 10 inches, but 5 to 8 inches was commoner. At most places in the limesands a zone of slight organic staining extended another 10 to 19 inches beyond the humus layer. Roots were common to depths of 2 to 3 feet and have been encountered at depths as great as 4 feet below the ground surface in freshly dug pits.

As will be brought out by the botanist's report, vegetation zones show a general relation to soil types, especially in certain elements of the ground cover. However, an overriding effect is exercised on vegetative patterns by exposure to wind and salt spray, by the nature of the ground water (related to width of land, distance from sea or lagoon, and height of land), and by artificial factors.

Intertidal environments except reefs

Under intertidal environments are included beach areas, flats that are mainly intertidal, and bars. Reefs, and areas that range from intertidal to lagoonal are considered elsewhere.

The biota of the beaches, tide flats, and bars is generally distinctive. Sand beaches support little in the way of a megafauna--only ghost crabs (<u>Ocypode</u> sp.) and, at some localities on the lagoon side (e.g. C-38), closely packed layers of a small edible pelecypod (<u>Atactodea</u> sp.) an inch or two below the surface of the sand in the mid-tide zone. On rocky beaches, on both seaward and lagoonward sides, a neritid snail close to <u>Nerita plicata</u> Linné is commonly very abundant, and a high-spired littorinid probably referable to a species of <u>Melaraphe</u> is locally abundant. On rocky and gravelly seaward beaches the common tropical Pacific scavenging crab <u>Grapsus grapsus</u> (Linné) is abundant. Sand bars are very nearly devoid of a megafauna, but burrowing sipunculids may be found. The intertidal flats display a wide biotal variation that will not be discussed here, but some elements of which are noted in Appendix B.

Outer reef

An atoll consists of a ring-shaped outer reef and a central depression or lagoon. In plan view the outer reef is generally irregular in outline and is interrupted and divided into segments by passes. In modern seas islands are commonly located on the reef platform. The lagoon ordinarily contains small patch reefs of a variety of shapes, and, in some places, submarine benches lie beyond the crest of the outer reef. By definition the lagoon of an atoll can contain no pre-existing land, but this would not exclude islands that might be founded on patch reefs. The ring-shaped outer

reef is the essential and most conspicuous feature of an atoll and the subject of the immediate discussion. Patch reefs will be considered under a following section on environments of the lagoon and leeward shelf.

A conspicuous feature of the outer reef, especially in the Gilbert Islands, is the difference between windward and leeward sides. With the exception of Butaritari (or Makin, Mŭ´gĭn) and Marakei, the atolls of the Gilberts show continuous wave-breaking reef and almost continuous land on their windward (east) sides. Their leeward (west) sides are characterized by irregular outer reefs and few or no islands. All passes into their central lagoons are to leeward. The windward reef flat of Onotoa (also observed parts of Tarawa and Butaritari) is generally exposed at low tide and is veneered with algae. The leeward reefs are commonly submerged for a few feet over most of their area, even at low tide. At many places they show relatively vigorous coral growth--locally even continuous veneers of closely packed living coral. A feature of some Gilbert Island atolls, established for Onotoa but also noted at observed parts of Tarawa and Butaritari, is that at least the upper part of the reef frame was built primarily by the blue coral *Heliopora*, an alcyonarian, and not a typical stony coral or scleractinian (see also Finckh, 1904, p. 136). That this may be commonly or even generally true for the Gilbert and Ellice Island groups is further suggested by the observations of David and Sweet (1904, pp. 66-70) at Funafuti. Here *Heliopora* was the frame builder to a depth of 40 feet below high tide in the main bore and occurred in the cores to depths of at least 100 feet.

The ecologic niches of the outer reef may be grouped into those of the reef slope, the reef front (with coralline ridge and surge channels), and the reef flat, the greatest variation being in the reef flat environment.

The relationships of the most persistent recognizable units are shown on figure 3 (profiles 2 and 5)--these being the green alga zone, the red alga zone (including back ridge trough), the coralline ridge, and the benched reef slope of the windward reef.

Intertidal to lagoonal environments

At Onotoa, flats and shoals with extensive growth of the marine grass Thalassia, as well as generally barren rocky flats and shoals, overlap widely from the intertidal to the lagoonal environment and are thus separated from both. Coral veneered rocky shoal bottom is strictly of the shoal lagoon, but it is so closely related to adjacent sparsely coralliferous rocky flats and shoals that it is included with the intertidal to lagoonal environments as a matter of convenience. It is also convenient to include under this heading certain enclosed inlets which, although permanently inundated and similar to the lagoonal units, are separated from the lagoon proper by extensive tide flats.

Environments of the lagoon and leeward shelf

The area here referred to as the leeward shelf is that which extends north and south from the anchorage, beyond the main passage between lagoon and anchorage (see figure 2). Ecologic zones and deposits of the lagoon and leeward shelf may be roughly delimited according to variations in areal importance of patch reefs or veneering coral growth as contrasted with lime-sand bottom. They may also be further broken down on the basis of differences in the dominating reef-building organisms. The probable nature of the formerly luxuriant growth of Heliopora is well illustrated in the present lagoon by areas of Heliopora patch reefs and limesand.

The effect of certain fish in the production of lagoonal sediments is of special interest. Darwin observed that fish browsed on coral, and Couthouy (1844, p. 97) was aware that lagoonal sediments might "partly arise from the excretions of certain fishes." Safford (1905, p. 90) and Newell et al. (1951, p. 13) also observed fish nibbling on coral, but Finckh (1904, p. 141) states that "although a large number of kinds (of fishes) were watched in the neighborhood of coral, in no instance were they seen to browse on it." There is no doubt, however, that fish do browse on coral, and they probably are important contributors to the sediments around reefs.

The scarids (parrot fish), with their parrot-like jaws, and the acanthurids (surgeon fish), chaetodontids (butterfly fish), and pomacentrids (damsel fish), with their fused comb-like teeth, appear to be primarily browsers on soft algae. Significant to sedimentation is the fact that, in course of feeding, fish from these families scrape off thin layers of the dead calcium carbonate substrate. This was verified by examination of their gut contents. These fish are so numerous and active that they probably produce a fairly constant rain of this fine $CaCO_3$ debris, and, indeed, schools of scarids commonly defecate great clouds of it when startled. In course of time this must represent a considerable contribution to the lagoon sediments.

A coarser sedimentary product is added by the balistids (trigger fish) and monocanthids (file fish), which are armed with a massive dentition of grouped biting teeth, and by the tetraodontids (puffers), which have parrot-like jaws similar to those of the scarids. Their stomachs contain the fresh tip ends of branching corals up to 5 by 10 millimeters and some have yielded chunks of crustacean tests and spines and plates of echinoids, as well as

algae. They have been observed actually to bite off the tips of coral branches, and the fresh pieces of coral in their guts are free of fleshy parts. Doubtless these fish provide a significant part of the coarse fraction of lagoonal sediments.

It is believed that fish are more important in the production and trituration of lagoon sediments than either echinoids or holothurians, the two groups that are most frequently cited as organic sediment producers. In making this argument I mean, of course, to emphasize a commonly neglected or unrecognized factor in lagoonal sedimentation, not to deny the significance of other factors. The calcareous joints of the green alga Halimeda locally bulk large or even dominate in lagoonal sediments (e.g., David and Sweet, 1904, p. 65), and Foraminifera and coralline algae contribute significantly to these sediments through their dead shells and joints. The spicules of gorgonians and other alcyonarians (Carey, 1918, 1931) and the tests of ostracodes are likewise contributing elements. Detrital products strictly due to abrasive wave action and derived from both outer reef and patch reefs also contribute to the lagoonal sediments, but probably do not bulk as large in their overall mass as might be supposed.

The foregoing and other matters related to the ecologic zones and deposits of the lagoon and leeward shelf will be considered more fully and critically when laboratory studies are completed. For the present it must suffice to note that the obvious variations in the shallow lagoonal environment comprise differences in density of concentration of patch reefs. Patch reefs are very abundant and locally almost continuous toward the leeward reefs and passes and gradually decrease in number toward the island mantled windward reef platforms. Linear to irregular areas of bare limesand alter this gradational sequence only locally.

Beachrock results from lithification of beach debris in the intertidal zone owing to factors not fully understood but apparently peculiar to saline waters that are saturated with calcium carbonate. It is common on tropical sea beaches. It characteristically has the slope and mechanical composition of the constituent beach materials, whatever these may be. Beachrock is mentioned in most reports that discuss the shore-zone geology of tropical islands and has been discussed at length in several papers. A recent summary is by Emery (in Pac. Sci. Board, 1951, p. 34). It is evident that cementation of beach sands to make beachrock results from interstitial precipitation of calcium carbonate in the intertidal zone, but the mechanism of such precipitation is not agreed upon. The ensuing discussion will emphasize the importance of algae in beachrock formation.

Onotoa is an almost ideal laboratory for the study of beachrock, for hard beachrock and bonded limesand occur there over large areas. Bonded limesand, considered to represent incipient beachrock, was found on lagoon beaches, in tide pools and spray pools, and as broad carpets in tide flat areas. It was not found anywhere on the seaward beach at Onotoa. On some tide flats the penetration of fairly solid beachrock by numerous burrows of a small red-clawed fiddler crab (Uca sp.) strongly suggests that the burrows were dug prior to induration of the rock. Everywhere that bonded limesand was found on Onotoa it was observed to be encrusted with living blue-green algae of several genera and species (see descriptions in appendix B). These algae apparently bind the beach and tide flat sands at the surface and, through their biologic activities, may cause or accelerate interstitial precipitation of calcium carbonate beneath. Some samples of the supposed incipient beachrock show successive alga-capped layers or laminae, and it

looks very much as though the algae play the important function of holding the sands in place until they can be indurated.

I am satisfied that the formation of beachrock in protected localities is brought about by, or greatly accelerated by, the activities of blue-green algae and hope to document this fact more fully in a later report. It is difficult, however, to see how ordinary blue-green algae could have a significant effect on the bonding of conglomerate beachrock on an exposed seaward beach. Perhaps the answer is that beachrock does not form on exposed beaches except in protected places or during times when wave action is very weak. A sample of firmly bonded gravelly sand containing numerous brass cartridge shells was collected on a seaward beach at Tarawa, but this had formed in a pocket behind ledges of older beachrock and was encrusted and ramified with soft algae. If any given locality were free from strong wave action only long enough for algal bonding of beach detritus to get a good start, cementation might continue when the locality again was exposed to more vigorous wave attack.

HYDROLOGY

Hydrologic observations made were limited by time, facilities, and staff. Several samples of ground water and one sample of sea water were taken for chemical analysis (not completed); some observations of movement of dyed water across and beyond the windward reef were made; and diurnal variation of pH, temperature, and chloride ion concentration was observed at selected localities. In addition, some determinations were made of total hardness, calcium hardness, and magnesium hardness, all "as $CaCO_3$," and of calcium and magnesium ion concentrations. Chloride was determined by titrating with silver nitrate and potassium chromate, and hardness factors were determined with stock hardness indicators and sodium hydroxide as described by D. L. Cox (Pac. Sci. Bd., 1951, pp. 22-26). Observations of pH were started with a Gamma electric meter using glass and calomel electrodes, but, owing to battery failure, it was necessary to complete this study with a Japanese-made (Mitamura) set of colorimetric indicators. Colorimetric indicators, unfortunately, are neither as reliable nor as finely calibrated as the electric meter.

In the ensuing discussion the term "chlorinity" refers to the concentration of the chloride ion (Cl^-) in parts per million of solution.

Ground water

Ground water in the permeable medium of an atoll island occurs as a lens of fresh water floating in hydrostatic balance on salt water below. As fresh and salt water are miscible, a zone of mixing occurs at the contact of the fresh-water lens with the salt water below. Various irregularities in the shape and integrity of the lens may result from openings, passageways, or

variations in permeability of the island foundation that accelerate or retard mixing. A ground water lens of this sort is called the Ghyben-Herzberg lens, after two of its early propounders, and it is succinctly discussed by Wentworth (1947).

The source of fresh water in the lens is rain. Given adequate rain and unvarying permeability, the thickness of the lens depends on its areal dimensions and the amount of loss through evaporation or artificial draft. As a result of the difference in density between about 1.000 for fresh water and about 1.025 for sea water, the thickness of the balanced lens, assuming no mixing, should be 40 times the height to which the balanced fresh water extends above sea level. In small islands or very narrow parts of long ones the fresh-water lens will be relatively thin and brackish. In large islands of medium and consistent permeability, assuming adequate rain, the lens will be thick and the water potable. In time of drought this fresh water, in parts of islands wide enough to have a reasonably thick lens, would be lost only slowly by diffusion, mixing, and outflow. Heavy draft without recharge, however, leads to salt-water invasion.

Ample demonstration that the ground water of Onotoa comprises a lens of the Ghyben-Herzberg type is provided by observed diurnal variations of the level of ground water at site C-2 (center of island, shower well at camp). This level fluctuated through $16\frac{1}{2}$ inches with a tide range at the time of about 4.3 to 5.5 feet, and its high and low stands followed the high and low tides with a lag of 2 to $3\frac{1}{4}$ hours. Obviously, the fresh water is affected by the tides and must be floating on interstitial sea water in the permeable sediments and rocks beneath.

Eight ground water samples were studied from an area about $\frac{1}{4}$ mile square and centering on the Government Station and our campsite (figs. 2, 3). This

area was selected for study partly as a matter of convenience and partly because the island at this place approaches the probable minimum width (1000 to 1400 feet) required to maintain a fresh-water lens continuously through drought periods of recorded duration.

Results of field tests on this ground water are given in table 3. Samples 1 to 5 were from wells dug and maintained prior to the arrival of the American field party. Sites C-1, C-2, and C-3 (fig. 3) were dug mainly to obtain ground water samples and geologic sections at regular intervals across the island. Sites 1, 2, 3, 5, and C-2 were about at the center of the island, whereas sites 4 and C-3 were halfway from center to lagoon beach, and C-1 was halfway from center to seaward beach. Of the five wells tested, the two--1 and 2--that showed lowest chloride concentrations and total hardness were at the center of the island, but one well toward the lagoon beach (4) provided potable water. Well 3, relatively high in chloride content, total hardness, and magnesium, and not good for drinking was also at the center of the island and only 225 feet south of well 2, a good well. The data of table 3, in combination with taste tests of other wells, indicate that a well toward the center of parts of the larger islands that are wider than about 1000 feet has a good chance of producing a fairly continuous supply of potable ground water under the normal draft of the native population. Wells in narrower land or near the beach are apt to be brackish. According to the principles of hydrostatic balance in the Ghyben-Herzberg lens, as the land is wider, the lens is thicker, and the chances of a sustained supply of potable water are better.

Irregularities in fresh-salt boundary relationships in the lens due to openings in the reef-rock foundation are to be expected, and the relatively

Well or site	pH Gamma meter	pH phenol red dye	pH thymol blue paper	Chloride (ppm)	Total hardness as $CaCO_3$ (ppm)	Ca^{++} (ppm)	Mg^{++} (ppm)	Temp. °C
1	7.66	—	7.5	262	418	98	42	29
2	7.98	—	—	264	429	70	62	29
3	7.40	—	7.7	989	693	93	112	28
4	—	7.7	—	633	532	75	84	26
5	—	7.7	—	640	548	88	80	26
C-1	7.48	—	—	—	—	—	—	23
C-2	—	7.5	—	—	—	—	—	23
C-3	—	—	7.7	—	—	—	—	—

Table 3. Properties of ground water on Onotoa

(Note that all pH readings were made during daylight hours, pH of wells with algae should fall at night)

high chloride and magnesium content of well 3 is possibly due to such an opening or passage. It is possible to predict the location of such openings only by methods that are prohibitively expensive with reference to the ease and cheapness of digging a shallow well. The practical way of meeting the problem of ground water supply in the Gilberts is to locate wells intended to supply drinking and cooking water at or toward the middle of islands more than 1000 feet wide and at least several thousand feet long. Some wells so located will encounter brackish water in any event, but they should be proportionately few.

Shallow sea and tide pools

Observations were made on diurnal variation of pH and temperature of water from a high tide pool and a spray pool on the windward sea beach, from a tide pool on the windward reef flat, from flow over the reef flat, from immediately offshore in the shallow lagoon, and from a spray pool with bonded limesand on the lagoon beach. The last mentioned, though a spray pool at neap tides, is a tide pool at times of spring tide. All sites observed were adjacent to the field camp south of the Government Station on the northern main island. In addition to pH and temperature, the concentration of calcium, magnesium, and chloride in parts per million was determined.

The beach zone pools at Onotoa mostly have flat bottoms, a large population of fixed algae, and a few snails (Nerita) and blennies. The tide pools of the inner reef flat have smooth, shallow, rounded bottoms, commonly elongated normal to the shore and with algae growing between rather than in them. The beach zone pools are considered primarily attributable to solution. The reef flat pools are probably in part abrasion features. Emery (1946) gives results of similar but more complete studies of tide pools at La Jolla, California, and provides references to previous publications on the subject.

The results of the observations at Onotoa are shown graphically in figures 4 to 8, and critical variations in hydrogen ion concentration are summarized in table 4. From these data it is clear that, excluding extraneous factors such as affected the high seaward tide pool of figure 7, temperature, chlorinity, and pH all show the same general pattern of diurnal variation. This pattern is a recumbent sigmoidal curve, rising to a peak during the day and falling to a low at night. Moreover, samples tested for Ca^{++} and Mg^{++} show that these properties vary directly with chlorinity.

The batteries of the electric pH meter gave out toward the end of the first set of 24-hour readings, but sealed water samples had been taken for all hours read and these samples were immediately checked with a Japanese-made (Mitamura) set of fluid and paper colorimetric indicators. These indicators showed consistent results following a diurnal variation curve similar to that of the electric meter but generally reading 0.3 to 0.5 unit higher and tending to flatten the curve slightly toward the peak. This check makes credible the general range of readings subsequently made with the colorimetric indicators, but also suggests that the colorimetric curve should be scaled somewhat lower than it actually reads.

Data from the shallow lagoon (fig. 4) and water in flow over the windward reef flat (fig. 5) may be taken as an approximate measure of the limits of normal variation in the very shallow marine waters of Onotoa. These show a range in chlorinity of 18,080 ppm Cl^- just before daybreak to 20,680 ppm Cl^- during the day. The pH (meter measured) ranges from 7.63 at midnight or early morning hours to 8.80 in midafternoon, and temperature ranges from 23.5° C just before daybreak to 34° C at midday. The lowest pH recorded electrically was 7.63 for water in flow from beyond the outer reef over the reef flat at midnight, and the highest was 9.05 for water in a then stagnant reef flat tide pool at midtide and midafternoon. This range is close to the range found

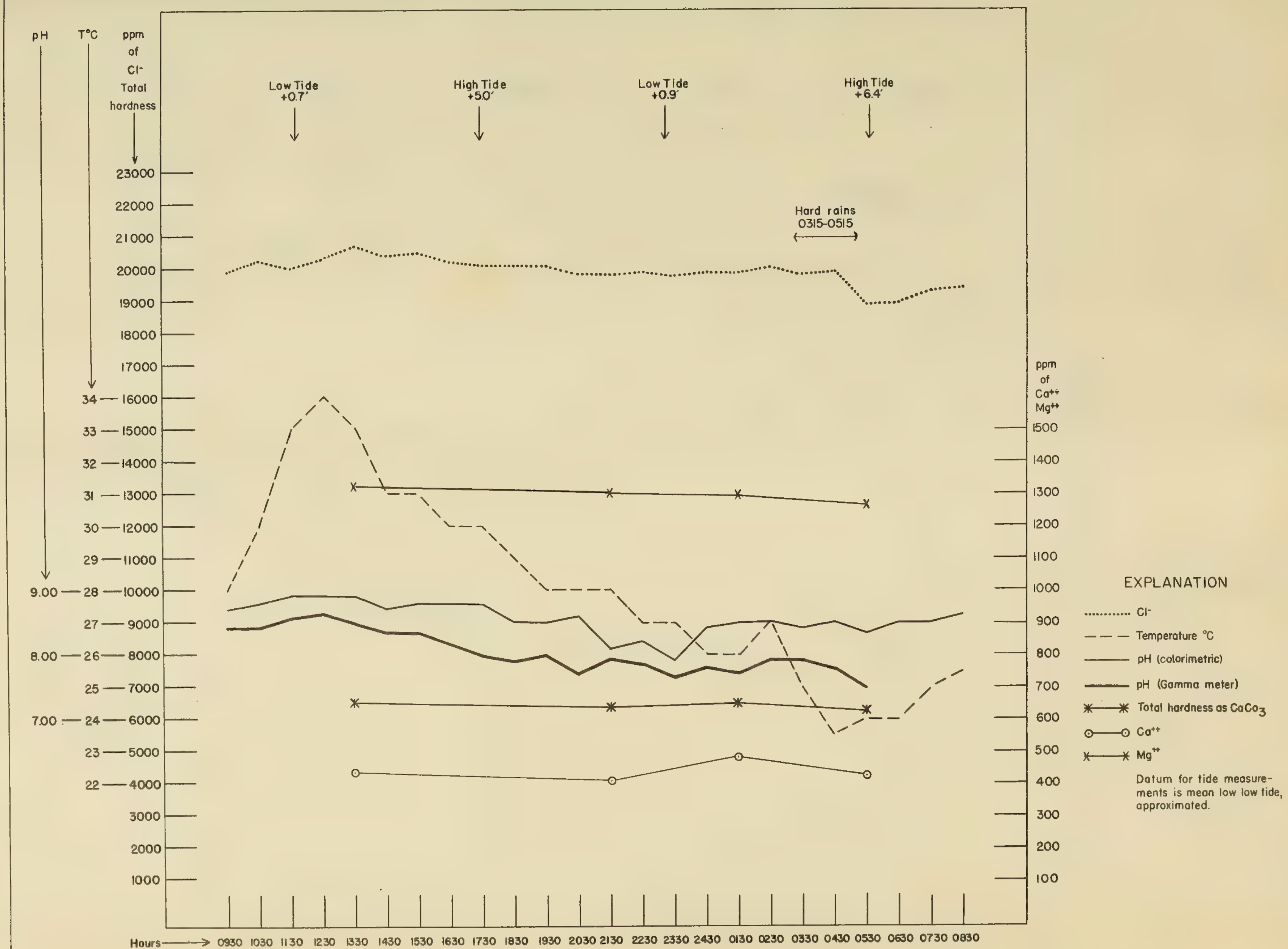

FIGURE 4. PROPERTIES OF SHALLOW WATER IN NEAR SHORE LAGOON (JULY 6–7, 1951)

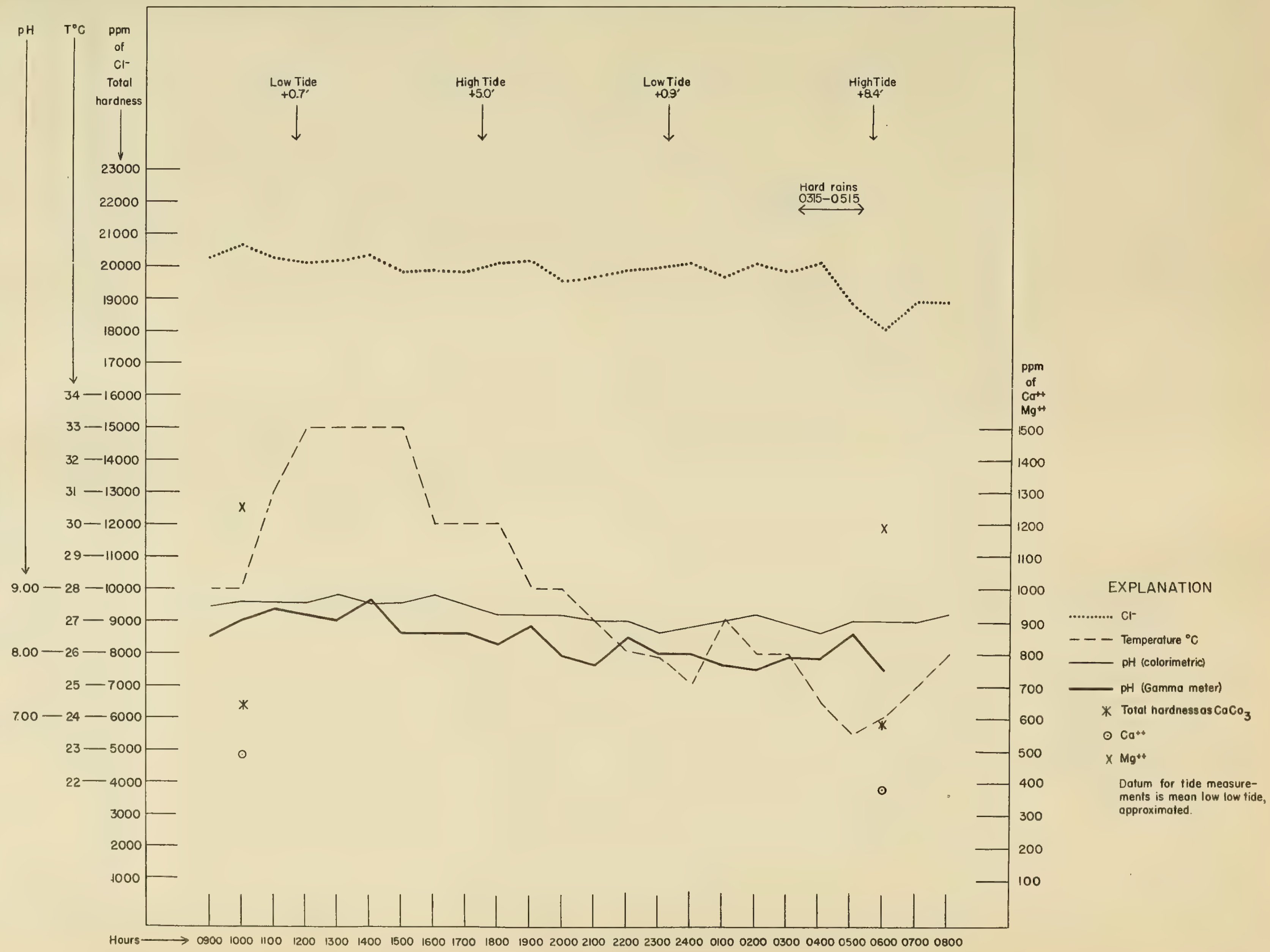

FIGURE 5. PROPERTIES OF SHALLOW WATER IN FLOW OVER WINDWARD REEF FLAT (JULY 6-7, 1951)

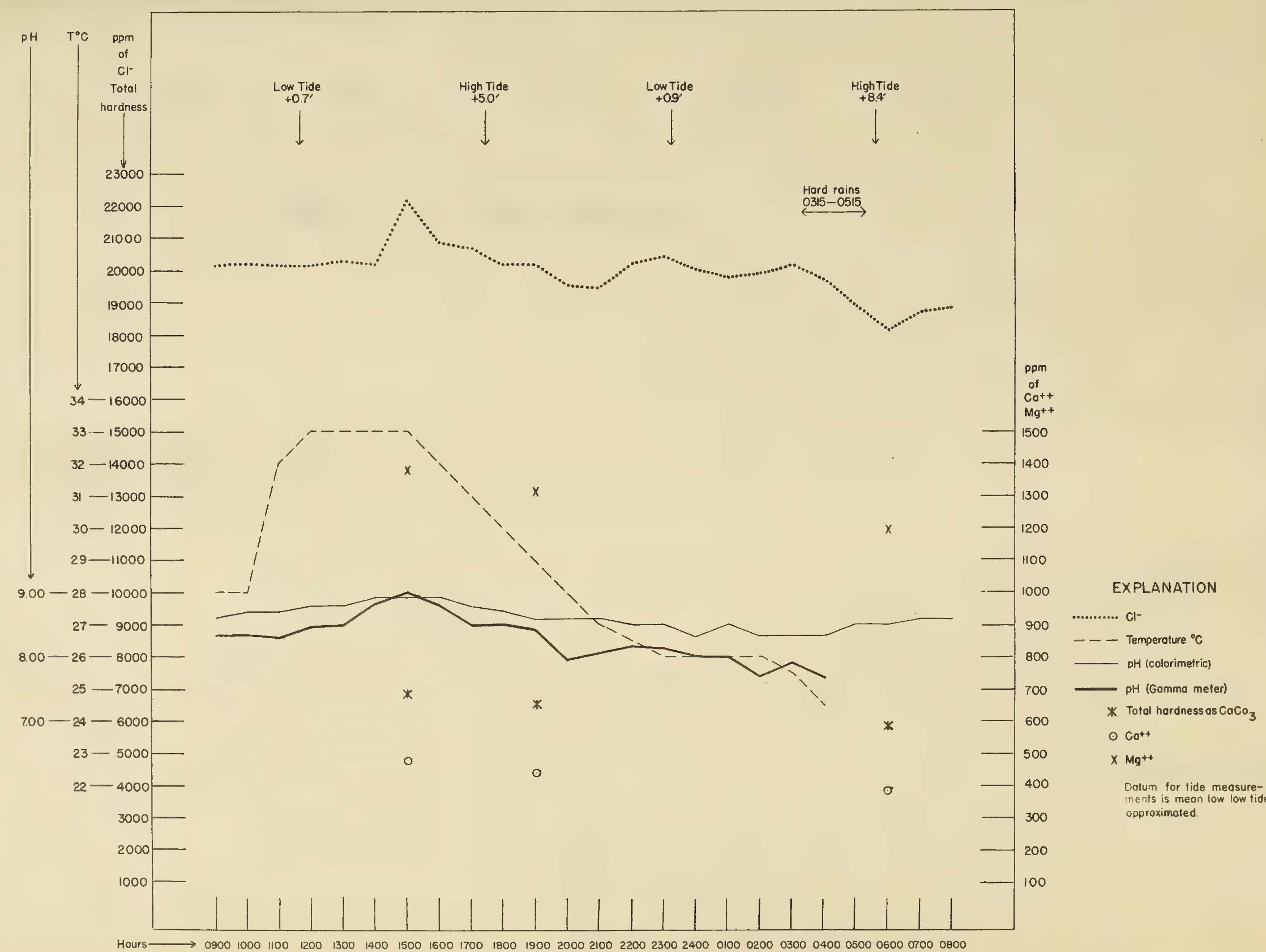

FIGURE 6. PROPERTIES OF WATER IN LOW TIDE POOL OF WINDWARD REEF FLAT (JULY 6—7, 1951)

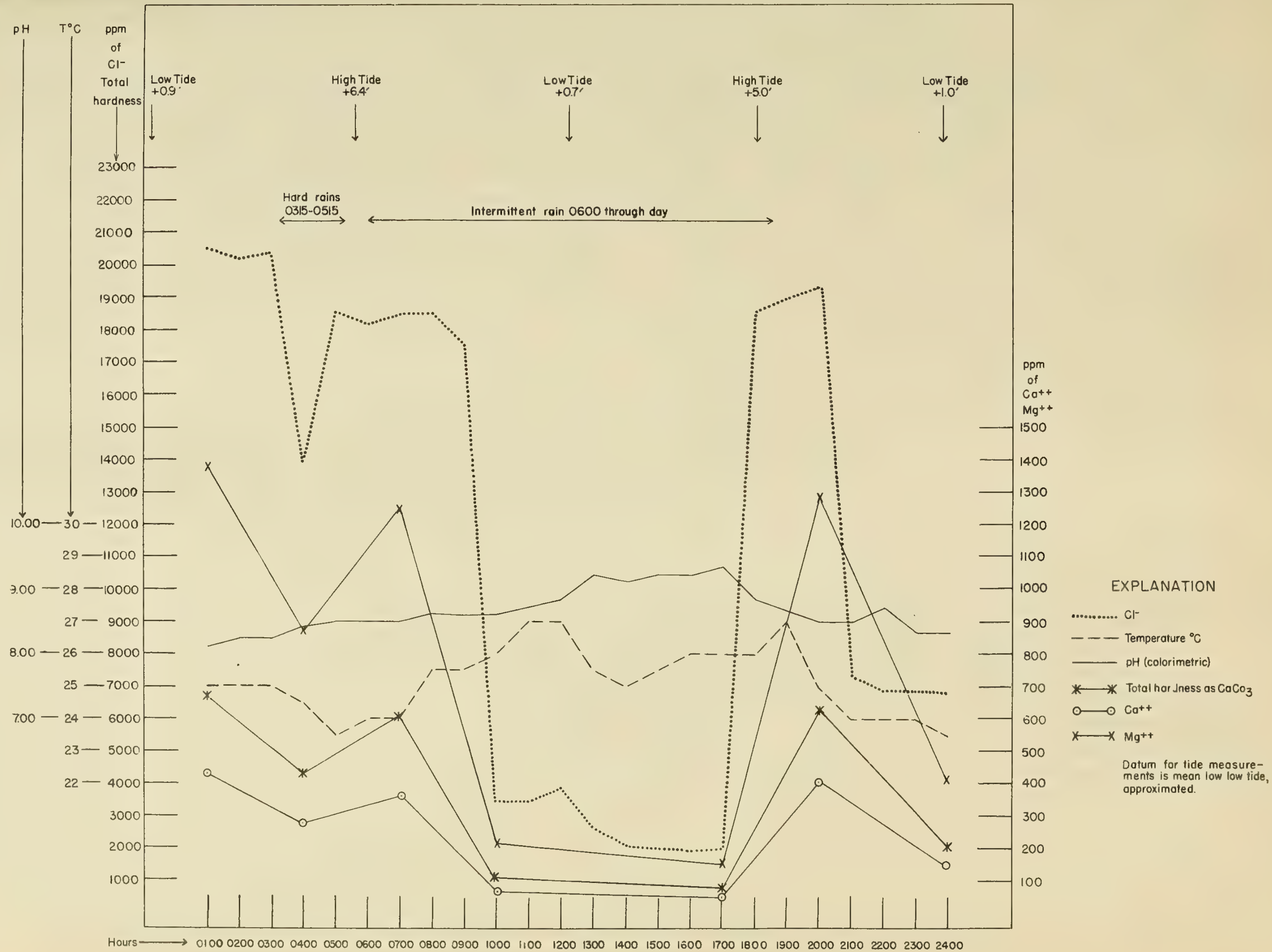

FIGURE 7. PROPERTIES OF WATER IN HIGH TIDE POOL OF SEAWARD BEACH AREA (JULY 7, 1951)

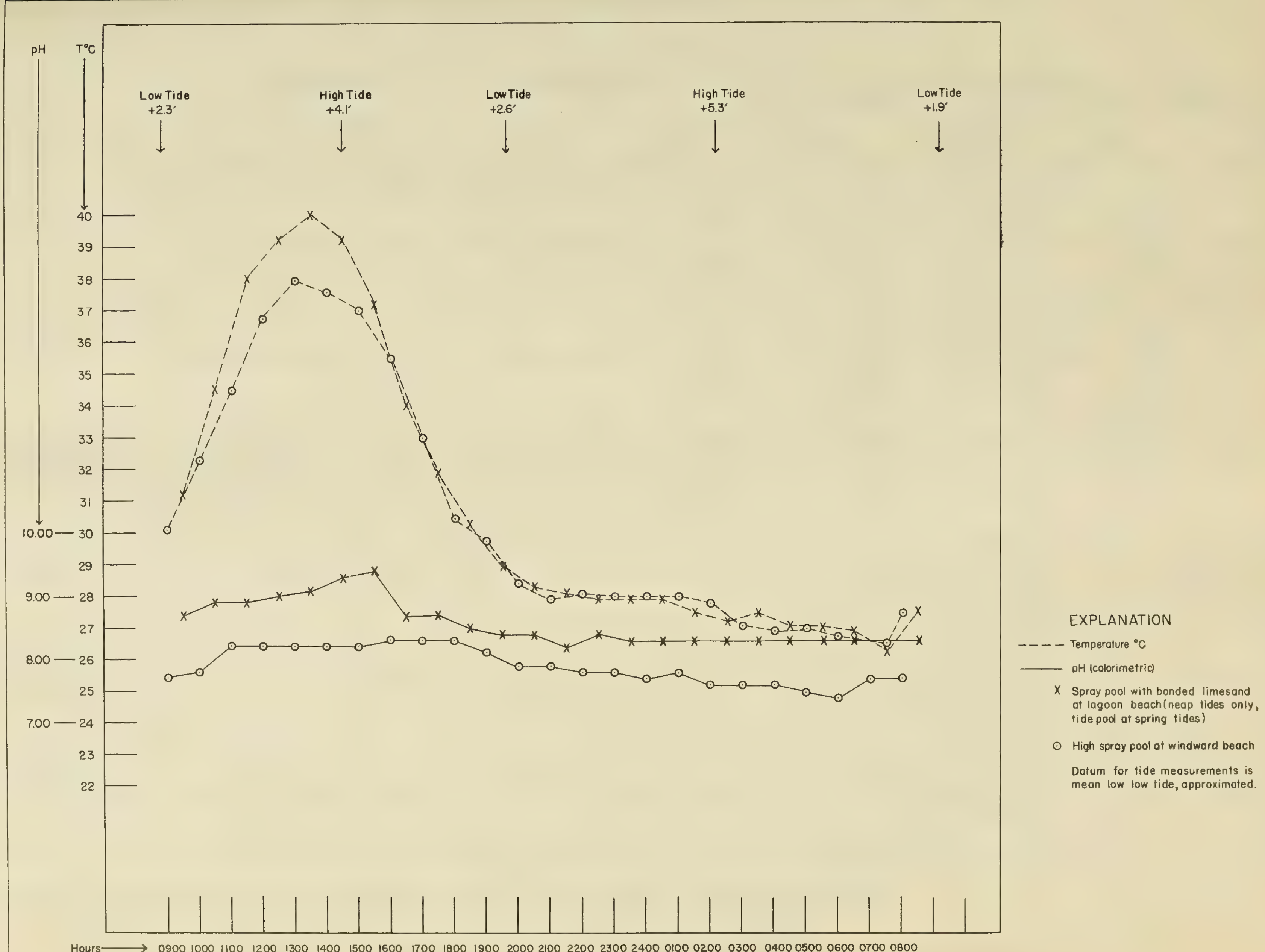

FIGURE 8. TEMPERATURE AND pH OF SPRAY POOLS (AUGUST 27-28, 1951)

Sample and figure reference	Minimum pH				Maximum pH				Periodic variations of pH							
									high				low			
	meter		colorimetric		meter		colorimetric		meter		colorimetric		meter		colorimetric	
	pH	time	pH	time	pH	time	pH	time	pH	time	pH	time	pH	time	pH	time
Shallow lagoon, fig. 4	7.63	2330	7.9	2330	8.63	1230	8.9	1130 to 1330	>8.0	0500 to 1900	>8.5	0800 to 2000	<8.0	2000 to 0400	<8.6	2100 to 0700
Windward reef, fig. 5	7.75	0200	8.3	2300 and 0400	8.80	1400	8.9	1300 and 1600	>8.0	0930 to 1630	>8.5	0830 to 1730	<8.0	1730 to 0530	<8.6	1830 to 0730
Low windward tide pool, fig. 6	7.65	0200 and 0400	8.3	2400 and 02-0400	9.05	1500	8.9	1400 to 1600	>8.2	0500 to 1900	>8.5	0700 to 2100	<8.2	2000 to 0400	<8.6	2200 to 0600
High windward tide pool, fig. 7	—	—	8.1	0100	—	—	9.3	1700	—	—	>8.4	0500 to 2200	—	—	<8.5	2300 to 0400
Windward spray pool (*), fig.8	—	—	7.4	0600	—	—	8.3	1600 to 1800	—	—	>8.0	1100 to 1900	—	—	<8.0	2000 to 1000
Lagoon (leeward) spray pool, fig.8	—	—	8.2	2130	—	—	9.4	1530	—	—	>8.3	0930 to 2030	—	—	<8.4	2130 to 0830

(*) Presence of decaying flesh in pool inferred to account for low pH readings.

Table 4. Variations in pH of shallow marine and beach zone waters

Sample and figure reference	Temperature °C				Chloride (ppm)				Hardness (ppm)		
	min.	time	max.	time	min.	time	max.	time	total hardness	Ca^{++}	Mg^{++}
Shallow lagoon, fig. 4	23.5	0430	34.0	1230	18,880	0530	20,680	1330	6225 to 6530	408 to 486	1266 to 1317
Windward reef, fig. 5	23.5	0500	33.0	1200 to 1500	18,080	0600	20,680	1000	5855 to 6375	380 to 486	1192 to 1254
Low windward tide pool, fig. 6	23.5	0500	33.0	1200 to 1500	18,080	0600	22,120 20,880	1500 1600	5855 to 6855	380 to 478	1192 to 1375
High windward tide pool, fig. 7	23.5	0500 and 2400	27.0	1100 1200 1900	1960	1600	20,480	0100	735 to 6685	46 to 422	151 to 1368
Windward spray pool, fig. 8	26.6	0700	37.9	1300	--	--	--	--	--	--	--
Lagoon (leeward) spray pool, fig.8	26.3	0730	40.0	1330	--	--	--	--	--	--	--

Table 5. Temperature, chloride content, and hardness of shallow marine and beach zone waters

by Emery (1946, p. 221, fig. 12) in a southern California tide pool with a temperature range of 14° to 26° C. A pH reading as low as 7.4 was recorded colorimetrically in a high windward spray pool at 6 a.m. and one as high as 9.4 in a lagoonside spray pool at 3:30 p.m.

Importance is attached to figure 7, representing a high seaward tide pool, because it shows an essentially regular diurnal variation curve of pH (colorimetric) through a period of fluctuating temperatures and dilution by rain (2.05 inches rainfall in 24 hour interval recorded on figure 7). Concentration of Cl^- in this tide pool fell 6000 ppm during hard rains from 3:15 to 5:15 a.m. However, it jumped back 4500 ppm with the first flushing wave of the high tide after the rains stopped and was kept at this concentration as long as the tide pool was reached by an occasional high wave. Concentration fell 15,000 ppm during a day of rains but jumped from 2,000 to 19,000 ppm as the tide reached peak and flushed the pool again. Chlorinity fell off markedly again at 9 p.m. as the tide receded and the pool was beyond reach of waves, but this drop must be explained by dilution from accumulated rain water seeping and trickling down from the irregular rock surface above the pool, for there was no rain at this time. Concentration in ppm of $CaCO_3$, $MgCO_3$, Ca^{++}, and Mg^{++} varied directly with Cl^-, and none of these concentrations showed any relation to temperature of pH.

Clearly, the pH of this tide pool is not significantly affected by or related to either temperature, chlorinity, or any of the variables that change with chlorinity. However, pH, temperature, and chlorinity do vary together in other situations (figs. 4 - 6, 8), and it looks as if they may vary in relation to some common factor. Sunlight provides a suitable common factor for temperature and pH, but its possible relation to the measured variations in chlorinity is not clear. Rain and variation in outflow from the fresh water lens with the tides are probably more important in accounting for chlorinity variations.

The general periodic variations of pH from relatively high during the day to relatively low at night is well brought out by table 4. During hours of sunlight marine plants (both attached and planktonic) use up CO_2 in photosynthesis, causing relative acidity, as measured by hydrogen ion concentration, to decrease, and pH, the inverse measure of hydrogen ion concentration, to rise. The reverse is true at night, when plants are not using CO_2 for photosynthesis, but both plants and animals are producing CO_2 through respiration. The CO_2 content of the water increases, hydrogen ion concentration rises, and pH falls. This is true of the high seaward tide pool, without regard to the extraneous factors that affect chlorinity and temperature, presumably because the variation in pH is organically controlled. Emery (1946, p. 221, fig. 2) clearly shows that diurnal variation of pH in tide pools at La Jolla is inversely related to CO_2 concentration. At the same place, he notes that variations in partial pressure of CO_2 from greater than in air at night to less than in air during the day indicate a larger range in CO_2 actually released and used than is indicated by measurements obtained.

Special interest in the diurnal cycle of pH variation derives from the part that tropical marine waters appear to play in solution and precipitation of $CaCO_3$. On the one hand, it is now common knowledge that such waters are normally saturated or supersaturated with $CaCO_3$ and therefore not capable of taking it into solution. On the other hand, the physical evidence of pitting and undercutting of tropical limestone shores is convincing to some (including myself) that normal tropical marine waters, under some conditions, can dissolve $CaCO_3$. Data obtained at Onotoa substantiate the conclusion already reached by Emery (1946, pp. 225-226) that these conditions are related to diurnal variation of pH in intertidal or very shallow waters with a high biotic density. During the day, CO_2 in shallow waters and tide pools is

being used in photosynthesis, pH rises toward a maximum of 8.6 to 8.8 or 8.9[3/] in open shoal water and 9.1 to 9.4[3/] in tide pools and spray pools, and precipitation of $CaCO_3$ should take place. At night, when the CO_2 content of these same waters is increasing, pH falls toward a minimum of 7.6 to 8.3[3/] in

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[3/] Highest readings colorimetric and probably in the range of 0.3 high.

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both open shoal water and tide pools, and it is probably at times of lowering of pH below about 7.8 to 8.0 that solution occurs. Emery (1946, pp. 222-225) has made the necessary calculations to show for similar data, though in a temperature range about 10° C lower, that solution at night and precipitation during the day is in fact possible within the observed range of pH. In arriving at the foregoing figures, data from the windward spray pool of figure 8 are discounted, because this pool was found to contain decaying flesh that doubtless accounts for its low pH. Of course, such things are common in tide pools and spray pools and would account for accelerated solution there.

That the effects of solution in shore zone areas are commonly more in evidence than precipitation is explained by the susceptibility of the minute aragonitic needles of the precipitated $CaCO_3$ to being flushed away by waves--or even blown away by wind at low tide from parts of the reef and tide flats that are exposed long enough to dry. Precipitated $CaCO_3$ in and near the shore zone of Onotoa appears to be preserved only on the elevated rims of certain tide pools and probably as part of the white encrustations on the surfaces of sediment-binding algae. Naturally, rain water, both as solvent and as flushing medium, accentuates the process of pitting and formation of tide pools and spray pools, and the effect of decaying organic matter is also important. However, neither rain nor decaying organic matter can have much

effect on the production of the undercut notches that are so common around limestone islands of the tropical seas.

Flow of water over the windward reef

The movement of powdered fluorescein marker dye was observed at several places over the reef flat, in surge channels, and over the benched reef slope seaward of the reef front along the windward shore near Government Station. Observations were made during a receding tide at a time of moderately strong surf, and all time intervals and quantities of dye were estimated.

About midway of the reef flat, which is about 800 feet wide here, a patch of dye about 20 feet in diameter on application spread out to about 80 feet wide by 100 feet long (elongated normal to shore) and moved altogether past the point of application in about 30 seconds. It then surged inward and outward with onshore surge and recession of waves but sinking as it moved and with dominant movement seaward along the bottom. Within about 10 minutes after application the dye was foaming in the surge channels of the coralline ridge.

About half a cupful of the powdered dye was applied just behind the coralline ridge and then observed from a raft anchored about 110 feet beyond the ridge on the benched reef slope. Traces of this dye foamed in the upper waters of the surge channels for a long while, but the bulk of it continued to sink and drift seaward for about 30 minutes. It gradually worked down to a basal layer of water and streamed out over the seaward sloping bench.

Dye was added to surface water about 50 feet seaward of the coralline ridge and surge channels. This dye worked outward and downward, streaming to the bottom at about a 30° angle in about 5 minutes. Within about 15 minutes it was all seaward of the shelf.

About three-quarters of a cupful of powdered dye was released at the bottom of a 6- to 8-foot-wide surge channel near its midlength, in about 10 feet of water. This dye surged up and down and spread to adjacent grooves, but it stayed in the surging waters for about 10 to 15 minutes before beginning to stream definitely seaward. It then streamed outward and downward across the sloping bench.

The foregoing observations show that there is a definite outward-moving bottom current in the shallow water over the reef flat and upper reef slope, at least at times of receding tide. Time did not permit repetition of the observations with an incoming tide, but I would expect the same pattern--the water that runs onshore at the surface because of the breaking waves must move offshore at the bottom. The fact of most importance is that this current is downward as well as outward, literally dragging the bottom, and at times of outflow between swells at the reef margin its force is memorable. Moreover, as this movement is perceptible even beyond the reef front at times of only moderately strong surf, it is probably considerable during storms. This is of importance in connection with the origin of reef front grooves and surge channels.

ORIGIN OF REEF-FRONT GROOVES AND SURGE CHANNELS

The fronts of most organic or limestone reefs that are exposed to the sea somewhere show a comb-tooth pattern of closely spaced grooves that are separated from one another by rocky buttresses. The parts of these grooves that transect the surf zone (and the coralline ridge if one is present) are called surge channels (Tracey et al, 1948, p. 867).

The origin of these groove-and-buttress systems is a vexing question, for they show features attributable to both biogenic construction and mechanical erosion. Ladd and others (1950, p. 413) have emphasized the importance of outgrowth of algal spurs to form the buttresses at Bikini atoll. They believe that although there probably "is mechanical abrasion during periods of exceptionally heavy weather...this does not seem adequate to explain the grooves as erosional figures." David and Sweet (1904, p. 81) explained them by a hypothesis of combined growth and erosion factors and Kuenen (1933, p. 80-81) believed that they were mainly constructional.

Newell et al (1951, p. 25), with reference to the Bahama Islands, inclined to the view that "the grooves are cut," and to judge from the fact that the grooves observed by them "are incised in oölitic country rock they evidently are erosional features." Before learning of Newell's views, studies of grooves and surge channels on Onotoa and previous observations of similar features on Guam, Saipan, and elsewhere had lead me to recognize erosion as important in the formation of the grooves. I have also seen, but not studied, grooves similar in plan to more conventional surge channels in the face of a basalt-floored bench just west of Haena point in northwestern Kauai, of the Hawaiian Islands.

In my opinion the grooves in many places are initially cut by outflowing undercurrents that carry tools of abrasion not available to the more spectacular inrushing surf. This produces the characteristic radial pattern of gravity flow. It is further suggested that most of this cutting followed falls of sea level, when reduction of bench surfaces provided maximum quantities of detritus for abrasion. Under proper light conditions air photographs of some shores (e.g., north Saipan) show several levels of offshore and even elevated grooves, not closely matching at their boundaries. These indicate groove-cutting at successive stands of sea level related to bench formation. Once a bench is reduced to equilibrium level, however, growth factors become relatively important. The abraded upper sides and crests of spurs then become veneered with growing coralline algae and corals, and the grooves may be masked over and generally closed or partly closed at the surface. This produces under-reef caverns and blowholes. Growth of algae and corals subsequent to groove cutting may be so extensive as to mask completely the evidences of abrasion, but the grooves and surge channels are found at so many places, and the radial pattern is so like the normal gravity pattern found on rilled rock beaches and elsewhere, that abrasion by outflowing gravity currents probably determined the basic pattern at many places where organic growth is the prevailing modern feature.

Many grooves and surge channels observed on Onotoa and elsewhere are undercut at their basal sides and floored with gravel, and many on the leeward coast of Saipan end in submarine potholes containing coarse gravel. The grooves are ordinarily most abundantly developed on windward reefs, but they have been observed in all quarters of the wind and at places are common on leeward reefs. Their degree of prominence is believed to be controlled by

strength of outflowing current, and thus surf, and by quantity of abrasive materials in transit. On the other hand, there are places where growth alone may produce the comb-tooth pattern. Both mechanical erosion and organic growth must be considered important in the origin of groove-and-buttress systems, the part played by each probably varying according to local conditions.

On Onotoa the grooves of the windward reef are almost limited to the surf zone and are thus synonymous with the surge channels, but traces of them run across the benched slope of the upper reef, masked by coral growth and debris. The front of the reef at the landward side of this bench is about 12 feet high and from the seaward side looks like the truncated spur-and-canyon topography of a steep-fronted and flat-topped mountain range or plateau. The surge channels range in length from about 50 to 80 and rarely as much as 120 feet. They are about 6 feet deep at midlength, and deepen gradually to about 8 feet at the reef front, with a downward dip of another 2 to 4 feet as they pass beyond the wave-breaking front of the reef. They range from 2 to 8 feet in width at the reef front and are undercut up to 1 foot on each side at their bases. Living algae and corals are abundant only at the crests and upper sides of intervening buttresses. The surge channels are floored with very coarse, mostly slabby gravel. At the reef front above this gravel during a period of relatively strong surf (swell measured 6 feet high, combers averaged an estimated 8 feet), the only movement experienced was an up and down with the swell. Down in the lower part of the channels, however, the swimmer is carried back and forth with the surge for as much as 15 to 20 feet at a time. Under these conditions only small pieces of the gravel were observed to move, the maximum size observed in movement being a slab about 8 inches in diameter that rocked gently back and forth without being transported from its original position. Slabs this size and larger, although well rounded, are mostly

coated with a fairly luxurious felt of living green algae, and it is evident that their rounding occurs only at times of storm or very heavy surf, with plenty of time between for growth of algae. Whereas there is apparently enough movement of the boulders and smaller gravel and sand to prevent growth of coral and coralline algae on the floor and lower parts of the surge channels (except locally at their mouths), the grooves are probably not being significantly enlarged at the present time.

It is suggested that most of the groove cutting in the reef front at Onotoa occurred during beveling of the present reef flat after the recent 6-foot eustatic fall of sea level.

On Onotoa, evidence for Recent lowering of sea level of the order of 5 or 6 feet is found in remnants of an elevated _Heliopora_ reef flat that occurs up to about 2½ feet above the inner edge of the reef flat, both on the beach and in wells (e.g., profile 5, fig. 3). The inner edge of the reef flat, in turn, is estimated to be 2 to 3 feet above present mean low low tide. At present the upper limit of living _Heliopora_ flats is about at low tide level. Similar occurrences of relatively elevated _Heliopora_ flats are also found at Funafuti (Sollas, 1904, pp. 21-24; David and Sweet, pp. 67-68 and plates). Further evidence of a fall of sea level of about 6 feet at Onotoa is provided by elevated cobble stripes of a sort that I have observed only on reef flats. These cobble stripes rise about 2 or 3 feet above a surface of cobble gravel that is about 6 or 7 feet above the present reef flat at the northwest end of Onotoa and are separated from the lower-lying present reef flat by a gravel rampart.

As a Recent world-wide 6-foot fall of sea level may be amply documented, the evidence on Onotoa is only part of the broad picture. The higher stand from which the present sea has receded is provisionally attributed by Stearns (1941, p. 780) to the postglacial optimum temperature cycle of 5000 to 7000 years ago, when water previously and now tied up in the polar ice caps was in the ocean. Fall to present sea level probably took place in two steps, the first a 3- or 4-foot drop and the second 2 or 3. Evidence for the second drop consists of a bench about 2 or 3 feet above the present reef flat at Onotoa and elsewhere (see Kuenen, 1933, pp. 66-70; Dana, 1872, pp. 333-346). No attempt will be made here to summarize the large literature on the question of recent eustatic falls of sea level.

Atoll islands characteristically consist of unconsolidated debris resting on a solid foundation. This foundation must be broad enough and high enough so that this unconsolidated debris can accumulate beyond the reach of strong wave action and be preserved there. The foundation may consist of a reef that has grown to the surface of the sea, or which, having grown to the surface, is left somewhat above normal sea level by recession of the sea.

On a surface which is exposed between tides, lime-precipitating and sediment-binding green and blue-green algae flourish, and even coarse clastic materials are quickly and firmly bonded together by interstitial calcium carbonate. This is demonstrated by the cementation of blocks in the stone-ring fish traps on the outer reef flat and by firmly welded bars of boulder conglomerate at Aonteuma and at the northwestern extremity of the atoll. Upon such an intertidal surface, also, debris tossed by the waves has a good chance of remaining in position at a distance from the reef front that varies with the transporting power of storm waves.

The first step in the building of an atoll island, then, is the erection by storm waves of a ridge or rampart of coarse gravel on a living reef flat or wave-cut bench. Seaward additions may, of course, be made to such a rampart by subsequent storms. However, evidence that the structure is essentially stable along a given line and under prevailing strength of waves is found in the fact that the gravel rampart is a single ridge at most places.

Building of land on the lagoon side of this rampart is harder to understand. That much of the work is done by wind is evident from the prevalence of dune sands at many places, but from where does the sediment come? In the sands of Onotoan islands it is clear from the abundance of the reef-flat dwelling foraminifer Calcarina that much if not most of the sand is derived

from the reef. The tests of *Calcarina* and other Foraminifera that inhabit the algal mats of the reef flat apparently were washed across the reef and drifted around the ends of and along the lagoon side of the gravel rampart by local currents. The washing of water across the reef through breaks in the rampart is a sufficient explanation of the currents, but they may be locally emphasized or negated by other factors, such as wind. In the job of island building these currents will be aided by wind-borne sand from tide flats or from bars produced by the currents along the growing shore in the lee of the gravel rampart.

The island should continue to grow in width as long as there is a base for it to spread lagoonward on and a supply of sediment for building. The latter is provided by Foraminifera and clastic particles of $CaCO_3$. Eventually, if the process continues, and currents do not keep the lagoon swept free of sediment, the lagoon must fill up and a large land area develop, as at Christmas Island, in the northern Line Islands. The height of an atoll island, insofar as it is not attributable to fall of sea level or to rampart building, depends on the height to which wind can build dunes on the base provided and from material at hand. Most atoll islands are relatively narrow and low, seldom anywhere exceeding 12 to 18 feet above the reef flat. In my opinion this indicates that they are also relatively modern phenomena. Several authors have suggested that the building of atoll islands has been accelerated by and perhaps dates from the Recent 6-foot eustatic fall, and such an interpretation would help to explain much of what is known of these islands, their biotas, and human migration in the Pacific. This recession of sea level would have resulted in an apparent elevation of near-surface reefs, providing excellent bases for land construction of the type the atoll islands show.

The common presence of a lengthwise depression or depressions within atoll islands is explained by the outlined manner of growth. In the early stages of the process the currents from the ends of the islands would tend to swing a little away from the gravel rampart and build a longshore bar on the lagoon side. Subsequent additions are made mainly to the lagoon side of this longshore bar, and sediment is added to the depression areas only as it may blow in or wash over bar or gravel rampart. On Onotoa the inner depression is only locally present. However, the process that results in an inner depression is perhaps exemplified at both ends of the atoll islands by the arcs of land whose sandy extensions curve around tidal inlets (fig. 2). The general pattern of distribution on Onotoa of sand toward the lagoon and gravel toward the sea, and of islands mainly to windward, also is consistent with the patterns of other atolls and with the process suggested. Storms that either washed across or broke through the gravel ramparts or swept in gravel from the lagoon may be called upon to explain gravel deposits lagoonward of the rampart. Stages in island growth, according to the scheme outlined, seem to be illustrated by the longitudinally paired island strips of Marakei Atoll in the Gilberts (Agassiz, 1903, pls. 149-150) and by the filling since 1900 of lakes in the central depression of Putali Island on Addu Atoll in the Indian Ocean (Sewell, 1936a, p. 77). Sewell also shows (loc. cit.), by reference to pumice lines, that "the inner beach of the island has advanced toward the lagoon by some 10 yards" between about 1885 and 1934.

The gravel rampart itself is commonly capped and at places completely concealed by a veneer or thick cover of fine-grained younger dune sands, blown ashore from the reef-flat area so recently as to show no humus layer, or thinly to veneer a humus layer below. This sand contains few Foraminifera and

is thought to be mostly derived at times of low tide from the fine $CaCO_3$ particles that adhere to the drying surfaces of the green and blue-green algae of the inner reef flat. The probability that even extensive windward beach-zone dune belts cap gravel ramparts seems strong enough to warrant the showing of inferred ramparts beneath such dunes on the island profiles of figure 3.

If the islands of Onotoa were mainly built on a platform residual from the 6-foot stand of the sea, and if this stand of sea is properly correlated with the postglacial optimum, all of these land-building events have taken place in about the last 4,000 to 7,000 years.

Atoll islands appear to be eroded primarily at times of great storms by breaching of islands or by the complete removal of islands and other sediments on stretches of the reef flat. If at least the seaward portions of the unconsolidated atoll sediments rest on a bench surface at a higher level than the reef flat, as at Onotoa, destructive processes should be retarded. Remnants of beach rock on denuded reef flats and buried or outcropping beach rock within land areas provide the best basis for reconstructing stages in the building and erosion of atoll islands, once given a foundation.

SHIFTS OF SEA LEVEL AND THEIR EFFECTS ON MODERN REEFS

The reef flats of Onotoa on which islands are situated are truncated surfaces. Green algae thrive on the inner reef flats. A few corals and abundant red algae are found on their seaward portions. Evidence that this surface has been truncated is found in the elevated Heliopora flat that dips under the islands. This surface is continuous, at places observed carefully, with an old, truncated Heliopora flat that runs across the present reef and is merely veneered with algae and the sediments which they bind and cement to rock. Evidence of a former stand of the sea about 6 feet above present sea level is found in the elevated area of reef-flat cobble stripes at the northwest end of Onotoa, and also in the elevated and truncated surface of the old Heliopora reef.

At Arno Atoll, in the southeastern Marshall Islands, coral growth flourishes at least on many parts of the reef flat. Of this atoll Wells (1951, pp. 4-5) has stated that there is no evidence of fall of sea level, and the same is commonly reputed to be true of atoll islands. On the other hand, evidence of fallen sea level has been recorded at Bikini (Ladd et al, 1950, pl. 4, p. 413), Funafuti (David and Sweet, 1904, p. 67-68), and Horsburgh atolls (Sewell, 1936b, p. 121). Regardless of the fact that independent confirmation cannot everywhere be found, there is widespread and impressive evidence not only of a recent 6-foot eustatic fall of sea level, but of a very recent fall of roughly $1\frac{1}{2}$ to 3 feet and of one or more former sea levels in a range of 16 to 35 feet above the present one (Daly, 1920; Daly, 1926, pp. 174-179; Kuenen, 1933, p. 66-70; Stearns, 1941, p. 779-780; Stearns, 1945). The 16- to 35-foot zone is obscure, and its effects on modern reefs can only have involved shoaling preparatory to later events of

more significance to their present aspects. The $1\frac{1}{2}$- to 3-foot fall seems best considered as a temporary stand in the lowering of the sea from the 6-foot level. There have also been local and perhaps eustatic positive movements of sea level, but positive eustatism for any given level is hard to demonstrate and relates only indirectly to the question here considered.

The evidence at hand suggests that the present superficial aspects of reefs are related to whether their surface was within 6 feet of sea level at the time of the 6-foot eustatic stand. If they lay below 6 feet, the drop in sea level would not have affected them markedly, and, if not sites of islands, they would presumably be flourishing organic reefs today. At such places no evidence of eustatic fall would be found except, in an indirect way, islands themselves, the construction of which would be facilitated by the shoaling of their potential foundations. If the surface of a reef were within 6 feet of sea level at the time of the 6-foot eustatic stand, it would be abraded and truncated with fall of the sea. It would be an area poor for growth of corals and crustose coralline algae, and veneered with clastic debris and soft algae or articulate corallines. Such reefs are found at Onotoa, Taraw, and Butaritari in the Gilbert Islands as well as in many other parts of the Pacific. In my opinion they are in themselves evidence of recent fall of sea level. Of course, it is to be expected that nontruncated reefs will be found in areas of truncation, for it is highly unlikely that all reefs of a given area or all parts of a given reef would have grown to uniformly shoal depths prior to the 6-foot fall.

A second feature of interest in connection with the Recent 6-foot fall of sea level is the already discussed development of grooves and surge channels in the present reef rim. It is here considered that such features at many or most places originally result from abrasion by gravity currents flowing

outward across the reef and equipped with abrasive tools provided by truncation of a relatively elevated reef flat. When such a reef flat is reduced to a stable level, or before, if conditions are favorable, growth of coralline algae and corals at the beveled reef margins is accelerated and eventually masks or even eradicates evidences of abrasion. The east end of Tarague Beach, at north Guam, is believed to exemplify an elevated bench in process of such reduction. For some unknown reason it, alone of all reef-flat areas seen on Guam, preserves numerous remnants of the older level between grooves that extend across the entire reef flat--as, of course, they should do until such time as lateral cutting processes reduce them to a general level.

A corollary of the contention that the 6-foot eustatic fall exerted a controlling influence on the superficial aspects of modern organic reefs is that one should be able to state, from the nature of its surface, whether or not any given reef area was within 6 feet of sea level at the time of the 6-foot eustatic stand. If it is sparse in living coral and veneered with green algae and clastic debris, and particularly if it is also a relatively smooth surface, it was probably truncated. If coral growth is vigorous and the surface irregular, it was probably not within 6 feet of the old sea level, or else it has grown up from a very severely beveled reef margin.

APPENDIX A--LIST OF REEF BUILDING CORALS AND HYDROZOANS

For the following preliminary identifications of corals and reef building hydrozoans from Onotoa I am indebted to Dr. J. W. Wells. The list given is composite for all localities and environments collected. Altogether it includes 26 genera and 50 to 60 species of corals and 2 genera and species of hydrozoans.

Scleractinia

Acropora humilis (Dana)

Acropora spp.

Astreopora sp.

Coscinarea columna (Dana)

Culicia

Cyphastrea micropthalma (Lamarck)

Echinophyllia aspera (Ellis and Solander)

Echinophyllia sp.

Echinopora lamellosa (Esper)

Favia stelligera (Dana)

Favia spp.

Favites sp.

Fungia concinna Verrill

Fungia scutaria Lamarck

Fungia valida Verrill--a new record

Goniastrea pectinata (Ehrenberg)

Goniastrea retiformis (Lamarck)

Halomitra philippinensis Studer

Herpolitha limax Esper

Hydnophora microconos (Lamarck)

Hydnophora rigida (Dana)

Leptastrea purpurea (Dana)

Lobophyllia sp.

Merulina sp.

Montipora caliculata (Dana)

Montipora foveolata (Lamarck)

Montipora verrucosa Lamarck

Montipora spp.

Pavona clavus (Dana)

Pavona varians Verrill

Pavona sp.

Platygyra rustica (Dana)

Platygyra sinensis (Edwards and Haime)

Plesiastrea versipora (Lamarck)

Plesiastrea sp.

Pocillopora caespitosa Dana

Pocillopora damicornis (Dana)

Pocillopora danae Verrill

Pocillopora elegans (Dana)

Pocillopora meandrina Dana

Pocillopora modumanensis Vaughan?

Pocillopora spp.

Porites andrewsi Vaughan

Porites lichen Dana

Porites lobata Dana

Porites lutea Edwards and Haime

Porites superfusa Gardiner

Porites spp.

Psammocora (Plesioseris) sp.

Seriatopora hystrix (Dana)

Tubastrea

Alcyonaria

Heliopora coerulea (Pallas)

Hydrozoa

Millepora tenera Boschma

Stylaster sanguineus Edwards and Haime

APPENDIX B--DESCRIPTION OF ECOLOGIC FIELD UNITS

Recognition of contiguous ecologic field units within a given general environment amounts to designating segments of a continuously variable sequence. Such units in large part express real central tendencies, but their boundaries are mostly indefinite, and to draw boundaries at all may be misleading. How to define the particular continuous variables in question and express them suitably on a map without recognizing suites of intergrading units is a problem yet to be satisfactorily solved. Pending such solution, or a reduction of categories on completion of laboratory studies and reevaluation of field data, the following descriptions may give the interested reader a more particular idea of the ecology of Onotoa.

Islands

Dune limesands

Younger dune sand. Mostly fine- to medium-grained, angular $CaCO_3$ sand. Humus layer incipient, thin, or absent.

Older dune sand. Similar to "younger dune sand," but with humus layer weakly to moderately well developed. In part rich in tests of foraminifer *Calcarina*.

Indurated dune sand. Indurated phosphatized (?) older dune sand.

Limesands other than known dune deposits

(Gravel intervals locally included in all types. Generally comprising most arable land and supporting thickest vegetation on Onotoa.)

Younger limesand. Fine- to coarse-grained sand, with humus layer thin or absent; locally includes gravel and wind-blown sand. According to local reports, the area of younger limesand and gravel on the point at Tabuarorae has been built since 1900.

Calcarina limesand. Sand of which 50% to 99% of the individual grains are tests of the foraminifer Calcarina. Generally with well-developed humus layer. Forms loose, well-drained soil with good capillary system. Favored for taro pits and breadfruit where ground water is sufficiently fresh.

Gravelly limesand. Sand with less than 50% Calcarina and with intermixed shelly gravel (abundant small Cardium, etc.) and small-pebble gravel.

Undifferentiated limesand. Fine- to coarse-grained sand with generally well-developed humus layer, with less than 50% Calcarina, and with little or no shelly gravel.

Limesilt grading to limesand. Mapped only in low, permanently damp areas. Generally wet and stiff. Humus layer poorly to moderately well developed. At places encrusted with caliche-like hardpan. Supports salt-tolerating shrub Pemphis (As well as poor coconuts, sparse Pandanus, etc.). Favored for retting pits because generally brackish water lies close to surface.

Limegravels

(Intervals of mostly angular sand locally included in all types)

Elevated flat-cobble stripes. Low ridges or stripes of cobbles oriented normal to beach line, similar to ridges that develop on modern gravel-veneered reef flats. No humus, few fines. Stripes are about 3 feet high, and bases of troughs between them are about 6 feet above present reef flat (hand level data). This is taken as evidence of a recent relative elevation of about 6 feet and correlated with the now well-documented Recent world-wide 2-meter eustatic fall of the sea.

Coarse coralliferous gravel. In part composed of large meandriform and astraeiform coral heads. Has little or no humus and few fines. Grades to "coralliferous pebble gravel."

Coralliferous pebble gravel. Fragments of branching Acropora conspicuous--also includes Heliopora and other corals, corraline algae, and mollusk shells and fragments. In coarser range grades to "coarse coralliferous gravel" and at many places includes areas or intervals of such gravel. In finer range grades to sands by increasing proportion of fines and reduction in size of gravel, and in such places approaches soil and vegetation characteristics of limesands.

Caliche

Caliche. Caliche-like limestone, not similar to beachrock. Found at one locality about 3 feet above reef flat level and behind sea-facing boulder rampart (north end of northern large island). Very thin crusts of caliche also occur at the surface of the enclosed Pemphis flats near this locality and in low places that are floored with wet limesilt.

Land bound areas of permanent brackish water

Brackish water ponds. Maximum depth 3 to 4 feet, blue-green algae abundant.

Blue-green algae flats. Areas of very fine $CaCO_3$ sediments rich in moderately to slightly brackish water cover nowhere exceeding 1-foot depth at normal tide level and in places barely enough to keep the ground wet. Covered with cauliflower-shaped nodules or mats of sediment-binding and lime-secreting blue-green algae.

Intertidal environments except reefs

Unconsolidated beach

Includes sand beach, gravel beach, sand and gravel beach, boulder beach, and outer beach.

Outer beach. Sand beach off lagoon side of southern main island that extends

beach proper beyond normal tide range and is exposed only at low low tides. Similar to "limesand flats" but narrower and sloping 3° to 5°.

<u>Rocky beach</u>
(Some units described here also occur inland and above normal tide range)

<u>Concordant beachrock</u>. Conformable with present beaches and certain tide flats. In large part little eroded, but commonly rilled and pitted with tide pools. Comprises limesandstone with dips 5° to 7° lagoonward on lagoon beaches and nearly horizontal on protected tide flat areas. On sea-facing beaches is limesandstone or coralliferous and algal conglomerate dipping 7° to 10° seaward.

<u>Nonconcordant beachrock</u>. Greater age than "concordant beachrock" suggested by occurrence at abnormally high levels, marked unconformity with present beach orientation, or unusually high degree of solution pitting in well indurated limesandstone. As mapped, probably in part includes "elevated reef-flat rock."

<u>Bonded limesands</u>. Weakly to strongly bonded limesands, commonly with a surface felt of sediment-binding (and lime-precipitating?) blue-green algae. At places consisting of successive layers separated by thin films of chlorophyll-rich sand that mark former exposed surfaces. Genera of algae provisionally identified from bonded limesands in the field by Dr. Edwin Moul are <u>Chroococcus</u>, <u>Gomphosphæria</u>, <u>Gleocapsa</u>?, and other genera of the Chroococales, as well as <u>Lyngbya</u> and <u>Scytonema</u>. At places the bonded limesands show aberrant dips, some up to 30° landward, where they apparently have formed as depression fillings or perhaps slumped into cavities by collapse from beneath.

Elevated reef-flat rock. Old Heliopora-flat rock or rock consisting of fragments of coral and coralline algae in limesand matrix. The matrix may be partly or entirely a beachrock, but it lacks dip, is unbedded or very obscurely bedded, and is thus more suggestive of indurated reef-flat detritus.

Enclosed intertidal flats

Enclosed limesand, limesilt, or limemud tide flats. Fiddler crab (Uca) borings abundant, and odor of H_2S commonly strong in freshly exposed sediments. Permanently damp and saline, but flooded only at highest tide. "Mud" is used provisionally and in the sense of probable grain size only; it has not yet actually been determined that any of this material is a limemud.

Pemphis flats. Similar to "enclosed limesand, limesilt, or limemud flats," but with cover of the salt-tolerating shrub Pemphis. Found at shoreward margins of "enclosed flats." The shrub Pemphis, of course, also grows upon the land itself, at the edge of the beach or even inland in low places that are subject to periodic flooding or where the ground water is brackish.

Mangrove flats. Similar to "enclosed limesand, limesilt, or limemud flats," but with cover of the mangrove Rhizophora. Generally flooded at same stage of all tides, but mostly "dry" at lowest low tides. Sediments generally in the limemud to limesilt size range and high in H_2S.

Mainly intertidal flats adjacent to lagoon proper

(Units under this heading grade to lagoon, reef, and beach units)

Coral-algal rock flats. Dead coral-algal bottom veneered to a large extent with limesand and with local pockets where the sand is thick. Displays

occasional concentrations of the turtle grass Thalassia (and mostly unattached Microdictyon) and in areas of standing water, sparse living coral that consists mostly of stubbily branching Acropora, Pocillopora, and smallish, hassock-like Porites.

Coral-algal rock and sand flats with Zoanthus. Similar to "coral-algal rock flats" just described, but with sand veneer somewhat more conspicuous and supporting extensive growths of the colonial anemone Zoanthus as well as considerable numbers of varied green algae.

Limesand flats. Relatively "clean" sand-covered tide flats, with generally sparse megafauna of burrowing sipunculid worms, ghost crabs (Ocypode sp.), the snail Polynices, occasional cones and terebras, and, at places, the anemone Zoanthus and the common holothurian Holothuria atra Jager. Plants are scarce, but algae occur locally on erratic rocks, and Enteromorpha has been tentatively recognized. Zone extends beyond beach proper to the zero fathom line (mean low low tide) or slightly deeper.

Sand and gravel flats. Tide flats of calcareous sand and gravel with green algae resembling Cladophora and Cladophoropsis, Dictyosphaeria, and Valoniopsis abundant in portions that remain wet at normal low tide. A few living corals are present locally.

Sand and gravel flats with coral. Similar to and grading to "sand and gravel flats" just described, but with scattered living coral, chiefly hassock-like Porites. Invariably wet when seen, and presumably water-covered except at lowest low tides.

Cobble gravel flats. Cobble-veneered areas mostly lagoonward from reef flats, including occasional boulder or pebble fractions. Components mostly angular. Unit also includes indurated cobble conglomerate flats, adjacent to or continuous with reef flats (as adjacent to Aonteuma and at north end of reef flat beyond this islet).

Pebble gravel flats. Areas veneered mainly with pebble gravels, but with some cobbles. Individual coarse fragments primarily angular.

Beachrock ribbed tide flats. Low ridges of old beachrock interspersed with dirty limesand flats, incipient beachrock patches, and circular patches of *Thalassia* (and *Microdictyon*). The common sea cucumber *Holothuria atra* Jager very abundant locally in pools and permanently wet depressions.

Bars and spits

(Continuously exposed or inundated only at highest high tides)

Includes sand bars and spits, pebble gravel bars and spits, boulder gravel bars, and bars of sand and gravel.

Outer reef

Grooved reef slopes. Upper slope of either leeward or windward reef front marked with conspicuous grooves normal to reef front and separated by buttresses veneered with living coral.

Papillated reef slopes. Upper slope of leeward reef front papillated with scattered, but more or less linearly arranged, patch reefs of living coral and coralline algae.

Benched reef slope. Upper slope of windward reef front, comprising a bench that slopes about 15° seaward from a depth of about 2 fathoms to the upper part of a 30° to 40° undersea slope at about 9 or 10 fathoms. Bench generally veneered with a mat of living and dead coral, the predominant types being stoutly branched *Pocillopora elegans* (Dana).

Reef front. Coralline ridge and surge channels prominent on windward side, but ridge is weak or absent on leeward side. The coralline ridge is low, purplish-red in color, and thickly crowded with masses and crusts of coralline algae such as *Porolithon* and *Goniolithon*. It runs along the

surf edge of the reef, is exposed at low tide, and is intersected by numerous channels through which surges the white water of the breaking surf. Presumably it was casual view of this reef front that led Setchell (1928, p. 1840) to state "the atoll of Onotoa...was composed, so far as visible, entirely of nullipore...largely if not entirely...Porolithon craspedium (Foslie) Foslie."

Red alga zone of windward reef flat. A permanently wet area of red algal growth landward from reef front. The outer part or subzone, an area of permanent standing water and locus of tidal fish traps, is called the back ridge trough. Here are scattered cabbage-shaped and branching masses and crusts of coralline algae such as Porolithon and Goniolithon and scattered large living heads of astraeiform and meandriform corals, as well as stubbily branching Acropora and Pocillopora. The green algae Caulerpa and Halimeda are found locally and sparsely in the back ridge trough. The inner part, or Jania subzone, of the red alga zone slopes up and grades to the green alga zone of the inner reef flat, their point of juncture being approximately defined by the inner edge of the fish traps. Biota of the Jania subzone dominated by articulate coralline Jania, with living Foraminifera of the genera Calcarina and Marginopora locally abundant. At places Jania subzone shows scattered, rolled coral boulders up to 16 inches in diameter, these boulders probably being broken loose within the back ridge trough.

Green alga zone of windward reef flat. Inner reef flat characteristically matted with green algae. Commonly divisible into outer, middle, and inner subzones. In the outer subzone the red alga Jania is an abundant holdover from the red alga zone, but green algae predominate. The intermediate subzone is one of flourishing green algae, and the inner

subzone is one wherein the green algae are whitened by encrusting bonded sediments or at places absent from the bare dead coral-algal rock below. At a distance these subzones seem sharply defined because of color differences, but they actually intergrade over rather wide intervals. Characteristic genera of algae throughout the green alga zone include Cladophora or Cladophoropsis, Valoniopsis, and Dictyosphaeria. At many places this zone is strewn with scattered, rolled meandriform and astraeiform coral heads up to 16 inches in diameter, these boulders probably being derived from the back ridge trough of the red alga zone.

Leeward reef flats. Lagoonward portion generally dominated by green algae; seaward portion characterized by abundance of articulate coralline Jania, crustose corallines, and scattered sturdily branched Acropora and Pocillopora.

Gravel and sand veneered reef-flat areas. Dead or decadent reef flat veneered with angular gravel of pebbles, cobbles, or boulders, and with a conspicuous fraction of sand. Living corals few.

Cobble and boulder veneered reef-flat areas. Dead or decadent reef flat veneered with cobbles and boulders. Sand inconspicuous.

Flat-boulder veneered reef-flat area. Chaotic coralliferous flat-boulder gravel on windward reef flat.

Gravel veneer on dead reef-breccia. Rough, angular, coralliferous cobble-pebble gravel with some boulders. Veneers surface of coral debris breccia that presumably represents old reef flat. At places old reef-breccia is bare, with no veneering gravel. Mostly covered only at high tide. Developed primarily between the two main islands.

Calcarina-Marginopora reef-flat areas. Protected reef-flat areas matted with living Foraminifera of the genera Calcarina and Marginopora, and with green algae, the Foraminifera commonly entangled in the algae. Scattered boulders and cobbles are common locally. A few specimens of the common black sea cucumber Holothuria atra Jager are found in permanently wet pockets.

Heliopora reef zone. Living Heliopora in essentially continuous and generally thickly arborescent reef growth, with Acropora and Porites secondary and other coral types minor.

Porites reef zone. Living reef area dominated by large flat-topped heads of Porites. Irregular coral growth on bottom having depths of several feet at low tide.

Acropora-Pocillopora reef zone. Living reef area of varied coral types dominated by varieties of Acropora and Pocillopora; corals thin out from reef flat toward lagoon or tide flats with increase in area of limesand bottom.

Varied reef zone. Reef area of abundant to scattered living coral growth of varied types on bottom of dead coral-algal rock that is at places extensively veneered with coral-algal gravel and limesand. Dominant living coral types are Acropora, Porites, Orbicella, and meandriform genera. Heads of coralline algae and pavement-type corallines locally abundant. Depths less than 1 fathom at low tide.

Heliopora flats. Living Heliopora scattered over and rising 1 to 2 feet above limesand bottom. Upper tips of Heliopora barely exposed at low tide. Minor gravel patches occur locally. The sea cucumber Holothuria atra Jager is common. Echinoids recorded include a large poisonous Diadema and the harmless Tripneustes cf. T. gratilla.

Decadent Heliopora flats. Includes scraggly truncated Heliopora, a few other species of coral, and green algae, interspersed on surface of limesand and gravel.

Dead Heliopora flats. Elevated, truncated, dead Heliopora reef flats. Essentially the same as the foregoing, but inundated only at high tide and thus with no living Heliopora.

Heliopora-Porites reef zone. Living reef area, mainly Heliopora, in large flat-topped heads crusted with Porites and crustose corallines.

Sandy reef zone. Mostly clean limesand with occasional living and dead coral at lagoonward margins of extensive leeward reef areas.

Intertidal to lagoonal environments

Thalassia flats and shoals. Dirty limesand with clusters or continuous mats of the turtle grass Thalassia. Commonly also with much of the green alga Microdictyon, the latter mostly unattached. The sea cucumber Holothuria atra Jager is locally very abundant.

Rocky flats and shoals. Bottom mostly of dead coral-algal rock patchily veneered with gravel and sand. Scattered but fair representation of living coral dominated by stubbily branching Acropora and Pocillopora and locally by hassock-like Porites. Circular patches of the marine grass Thalassia and the green alga Microdictyon occur locally at the beachward margin in the inner lagoon, and the brown alga Turbinaria is abundant at places. Holothuria atra is locally abundant.

Coralliferous rocky shoal bottom. Bottom similar to that of "rocky flats and shoals," but with fairly abundant living coral patches wherein stubbily branching Acropora and Pocillopora are dominant.

Enclosed inlet. Area walled off as pair of fish ponds. Supports thick growth of turtle grass *Thalassia* and many fish, including small sharks and an unknown fish that is much feared by the natives (apparently not a barracuda, to judge from the description, but was not seen by our field party). This area was not explored or sounded, but it is reported by the native, Kane, to be generally under 4 feet and nowhere more than 9 feet deep at low tide.

Environments of the lagoon and leeward shelf

The following units comprise a continuously variable sequence with more than usually indefinite boundaries:

Limesand bottom. Mostly clean limesand bottom at depths greater than 2 fathoms, living coral present locally.

Conspicuous lagoon patch reefs. Patch reefs of varied coral types and subordinate coralline algae, over 200 feet in diameter. Reef symbol on figure 2 used to indicate parts that are awash or nearly awash at low tide.

Limesand with scattered patch reefs. Mostly clean limesand floor, above which rise small scattered coral-algal patch reefs and pinnacles. Purely arbitrary and grades imperceptibly to limesand and patch reefs.

Limesand and patch reefs. Small patch reefs of varied coral types and subordinate coralline algae abundant but areally exceeded by limesand floor. Grades to "varied patch reefs and limesand," "*Heliopora* patch reefs and limesand," and "limesand with scattered patch reefs."

Varied patch reefs and limesand. Small patch reefs of varied coral types and subordinate coralline algae very abundant and only narrowly separated by areas of limesand floor.

Algal patch reefs and limesand. Abundant patch reefs of massive coralline algae and varied coral types presumably rising above limesand floor (bottom between reefs not observed or sampled).

Heliopora patch reefs and limesand. Abundant patch reefs consisting mainly of _Heliopora_ in tree- and candelabra-like growths that produce a forest-like underwater scenery. In part the _Heliopora_ patches are extensively masked by overgrowth of other coral types, and locally the patch reefs are of varied coral types. For the most part, intervening limesand bottom only narrowly separates individual patch reefs.

Varied bottom with scattered larger patch reefs. Subcircular patch reefs 100 to 300 feet in diameter scattered on bottom of limesand and limesilt with irregular low patches and small patch reefs of living coral and locally with abundant _Halimeda_. Depths between patch reefs mostly more than 3 fathoms, ranging to more than 7 fathoms locally. At shallow margin are several ridge-like patch reefs up to half a mile long.

Coral plantations. Coral and subordinate coralline algae essentially continuous or intimately intermingled with areas of dead coral on irregular bottom. _Acropora_ the dominant genus in areas observed.

Limesand patches in coral plantations. Extensive areas of limesand and minor patches of coral within coral plantations.

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ATOLL RESEARCH BULLETIN

No. 13

Preliminary Report on Marine Biology Study of Onotoa Atoll, Gilbert Islands

Part I

by A. H. Banner

Part II

by John E. Randall

Issued by

THE PACIFIC SCIENCE BOARD

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PRELIMINARY REPORT ON MARINE BIOLOGY STUDY

OF ONOTOA ATOLL, GILBERT ISLANDS

SCIENTIFIC INVESTIGATIONS IN MICRONESIA

Pacific Science Board

National Research Council

Part I	Dr. A. H. Banner University of Hawaii Honolulu, Hawaii February 20, 1952
Part II	Mr. John E. Randall University of Hawaii Honolulu, Hawaii March 4, 1952

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Thanks are also due to Dr. Preston E. Cloud, Jr., the leader of the expedition, for the use of the map he made of the island, and to R. Tucker Abbott of the U. S. National Museum for the identification of some of the molluscs.

PREFACE

The marine biological work on Onotoa is divisible into five portions:

1. The investigation of shallow water ecological associations, reported herein:

    A. The ecology of the windward reef.

    B. The ecology of the lagoon reefs and shores.

2. The investigation of the deeper water ecological associations, to be reported by Dr. Preston E. Cloud, Jr.

3. The investigation of the marine algae, to be reported by Dr. Edwin Moul.

4. The investigation of the ichthyofauna, reported by Mr. John Randall and appended to this report.

5. The native use of the marine invertebrates for food, reported herein.

My portion of the study, the marine invertebrates, was severely limited by an attack of blood poisoning and a subsequent attack of influenza that resulted from attempting to do field work when not fully recovered from the first illness; as a result of these two illnesses, over five of the ten weeks spent on Onotoa were lost and the investigations made were neither as thorough nor as extensive as planned.

The following reports are preliminary, and should be taken to show merely the extent of the work done. The identifications are field identifications and must be confirmed by experts, with the exception of some of the molluscs which have already been identified by R. Tucker Abbott of the U. S. National Museum; and no conclusions are incorporated in the reports. When these reports are published the deficiencies will be corrected.

PART I

I

WINDWARD REEF TRANSECT

The windward reef on Onotoa is found along the northern, eastern and southern shores of the atoll, presenting an almost unbroken barricade against the force of the prevailing waves. It varies in width from three or four hundred feet to over a quarter of a mile and is more extensively developed around the southern island than around the northern. As it is of quite uniform height, structure and biotic zones, a single transect across its surface was deemed to be indicative of the general ecology of the reef.

Conditions of the Reef

The inshore border of the reef is composed either of consolidated and eroded coral rock or moderately fine sand with the upper edge extending to the maximum height of the storm waves and the lower edge varying but usually about the 2.0 to 2.5 foot tide level. Beyond this steep shoreward area the reef flat extends to a uniform area of slight slope, with frequent small to large shallow pools of water left at low tide. The reef flat in the transect studied was 650 feet broad. Seaward of the reef flat is a depression, the back-ridge trough, between 50 and 100 feet wide and ranging in depth from about the + 0.2 to the - 1.5 foot tidal level. The final edge of the reef is the coralline ridge (or Lithothamnion ridge by previous workers), a rampart between 1.0 and 2.0 feet above the zero tide and 50 - 100 feet broad. Its shoreward edge presents an almost continuous front of reddish coralline algae, but on its seaward side soon develop deep fissures or surge channels at right angles to the shore that reach six or more feet below the surface of the reef and that are of varying width, widening as they reach seaward. The seaward edge of the coralline ridge thus separates into a series of

separate and depressed fingers that finally slope rapidly down to the growing reef surface below. The outermost reef or the reef shelf is relatively narrow, about three hundred feet wide, and slopes rather rapidly from about ten feet deep on the shoreward side to over thirty or thirty five feet deep on the seaward side; it consists of living coral growing in irregular mounds with areas between the heads strewn with dead coral fragments. Beyond this reef shelf the bottom drops suddenly away, at a slope of perhaps more than 45° and soon disappears in the turbid waters; this last zone was not explored at all.

The windward reef facing the trade winds sustains the almost continuous beating of the waves. At low tide the waves are broken against the coralline ridge and only slight waves are felt in the backridge trough. However, when the tide is high, only a portion of the strong waves is expended against the coralline ridge and the adjacent trough and moderate sized waves sweep across the reef flat, carrying enough energy to move coral rocks a foot or two in diameter.

The reef flat from the coralline ridge back is the evident result of the consolidation of a living coral reef, chiefly of Heliopora, by coralline algae; in almost all areas the old Heliopora is completely dead and covered with the algae to make an almost table-like top. This top, however, is pitted with small to large depressions, and in many areas perforated by burrows leading down among the old coral fronds.

Animals living upon the flat are subjected to many biological vicissitudes in addition to the action of waves. In the inshore area especially the reef flat is exposed to the air for several hours at a time at the lower low waters, and those animals that cannot migrate to the shallow pools must be able to withstand this period of dessication. Those animals in the pools, as well as those exposed to the air must also be able to withstand great changes in

salinity of their environment, for the high tide has the normal ocean salinity, while the low tide may expose them to torrential rains which would lower the salinity of the topmost layers at least to almost zero. However, because of the difference in specific gravity and the absence of agitation in these small bodies of water it is likely that the bottoms of the pools and the burrows in the rock especially maintain their normal salinity.

Probably the most pronounced physical change the animals are subjected to is the change in temperature for the dark reef surface on low tides is exposed for long periods to the tropical sun. At these times the water in the inshore pools become hot to the touch (studies on temperature made by Strasburg will be reported by Cloud): yet with the flooding tide the temperature will drop perhaps 15° in a few minutes.

Previous studies have shown that the oxygen content of the water over the reef at high tide and in the pools at low tide is always near if not above its saturation value. But as the temperature rises this saturation value, in grams of oxygen per liter of sea water, decreases rapidly, so the reef inhabitants must be able to adjust to less than normal oxygen.

Two biological conditions of the reef flat should be mentioned as influencing its ecology. In the first place the reef surface not in the small tide pools is covered in most areas by a dense algal mat that affords both food and protection for the inhabitants; this was particularly true in the middle and outer portions of the reef flat. Secondly, while few larger predators and scavengers like larger fish, lobster and crabs were found while the survey was conducted at low tide, they moved onto the reef at high tide.

Methods and Limitations of the Study:

The objects of the investigation were to find the transition of dominant forms over the reef surface, and, if possible, to designate sharply delimited

zones on the reef through a quantitative study.

On the main reef flat the study was conducted by laying out a series of continuous stations, twenty feet wide and fifty feet long, and within them areas extending the length of the station one or two feet wide. Within the smaller area all animals were collected and counted; the larger area was then inspected for larger but less common animals like the larger snails, sea cucumbers, etc. Then areas in the same tidal zone adjacent to the studied area were superficially examined to see if the zone selected was typical; it was found so in all cases.

In the inshore beach area, in the backridge trough, and over the offshore shelf no quantitative study was attempted because of difficulty in obtaining either enough animals in a typical area or because of the difficulty in laying out an area for study and collecting it (as in twenty to thirty feet of water). Because of poor tides and poor weather conditions when it was possible for me to do field work, almost no study was made on the coralline ridge at all.

The limitations of the study are:

1. The study is limited to macroscopic invertebrates; no microscopic forms of life nor any fish are considered. Mr. Randall did a parallel study on fish and will report it separately.

2. Concerned as it is with the dominant animals, this study omits the more rare animals.

3. All identifications of animals are but field identifications, and will be corrected upon the identification by experts.

4. The study is limited by necessity to the more superficially occurring animals; it was impossible to explore the tubes reaching down from the consolidated surface of the reef.

5. No statistical checks have been applied to the quantitative results, and they should be accepted merely as rough indications rather than accurate statistics; in other words, a similar section two hundred feet away might give different figures, but would show the same trend.

Transect

Area A-0; Shoreward beach.

The well-demarked beach extends from about 2.5 feet to about 8-10 feet above the zero tide zone. It is divisible into two different habitats, the sand beach composed of loose and shifting sand, and the rock beach consisting of consolidated coral and beach rock, eroded and with some small tidal pools.

The sand beach is the habitat only for Ocypode ceratophthalma, the "ghost crab" that lives in deep burrows by day; also at night terrestrial hermit crabs migrate down to the upper zones of the beach.

The rock beach is inhabited by Grapsus grapsus in fair numbers, some identified hermit crabs, and large numbers of *Nerita plicata (species marked * indicates the identification has been confirmed by R. Tucker Abbott.)

Areas A-1 to A-14.

These stations covered the reef-flat and present roughly the same type of substrate. The surface is relatively smooth, being built up by the consolidation of the individual heads and fronds of coral by coralline algae. Its surface is pitted with small shallow depressions in which water stands at low tide; these are usually less than a square foot in area and not over about three inches deep. The exposed surface of the coral and in some areas the tidal pools, are usually covered with a more or less dense growth of algae (to be reported by Dr. Moul). The exceptions to these generalizations are in the back-ridge trough (areas A-13 and A-14) where the surface is below the level of the lowest tides. Areas A-7 and A-8 and A-9 were at least in part covered by a single extensive tide pool; in these areas a few living pieces of Heliopora were still growing uncovered by coralline algae.

TRANSECT, WINDWARD REEF FLAT

Stations A-1 to A-14

In the tabulations below those animals not quantitatively estimated and those animals that are rare, scattered or very irregular in their occurrence (as would be those found only in the occasional loose coral boulders) are indicated by <u>P</u> for present.

Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Distance from beach	0-50	50-100	100-150	150-200	200-250	250-300	300-350	350-400	400-450	450-500	500-550	550-600	600-650	650-700
Height above 0.0 tide zone	2.4	2.2	2.0	1.8	1.6	1.4	1.2	1.0	1.0	0.8	0.6	0.4	+0.4 to -0.2	-0.2 to -1.4
Approximate percentage covered by tidal pools.	70%	30%	30%	50%	30%	30%	80%	100%	90%	70%	80%	70%	20%	100%

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PORIFERA														
Black Sponge	-	-	-	-	1	80	20	40	60	-	1	120	-	-
Purple Sponge	6	11	3	1	40	100	40	-	-	-	-	-	-	P
Yellow Sponge	-	-	-	-	-	-	-	-	-	-	-	-	-	P
COELENTERATA														
Heliopora sp.	-	-	-	-	-	-	-	2P	5P	-	-	-	-	-
Zooanthids	-	P	-	-	-	-	-	-	-	-	-	-	-	-
Sea Anemone	60P	-	-	-	-	-	-	-	-	-	-	-	-	-
Porites lobata	-	1	-	-	-	-	-	-	20	100	20	240	4P	-
Porites (papilliform)	-	-	-	-	-	-	-	-	-	-	-	-	-	P
Pocillopora meandrina	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Acropora sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	10
Orbicella	-	-	-	-	-	-	-	-	-	-	-	-	P	P
Goniastraa	-	-	-	-	-	-	-	-	-	1	-	20	-	-
Platygyra rustica	-	-	-	-	-	-	-	-	-	-	-	-	-	P
PLATYHELMINTHES														
Polyclad	-	-	1	-	-	-	-	-	-	P	P	-	-	-

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
NEMERTEA														
Nemertine	-	-	-	-	-	-	-	-	-	-	-	-	-	P
ANNELIDA														
Eurythroe sp.	-	P	-	-	-	-	-	-	-	P	40P	1P	-	-
Other Errantia	-	P	P	11P	P	P	-	-	-	P	-	120P	-	P
Tubeworms with foraminiferal tubes	-	P	P	-	-	80P	4P	P	P	-	-	-	-	-
Sipunculus sp.	-	P	P	P	P	P	20P	-	-	P	-	-	-	-
CRUSTACEA														
Stomatopoda (Pseudosquilla ciliata)(?)	-	P	-	1P	1P	-	-	-	-	P	P	80P	-	-
Crangon sp.	-	P	17P	70P	120P	-	20P	20P	P	P	140P	140P	P	4P
Synalpheus sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	1P
Shrimps, other	-	-	-	-	3P	-	-	40P	-	-	-	-	-	P
Callianassa sp.	-	-	-	1P	-	-	-	-	-	-	-	-	-	-
Paribaccus sp.	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Hermit crabs	800	87	689	1500	3400	3900	1720	111	60	-	-	-	-	-
Dromia sp.	-	-	-	-	P	-	-	-	-	-	-	-	-	-

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Thalmita edwardsii	-	-	-	3P	40P	-	-	-	-	-	-	-	-	-
Trapezia	-	-	-	-	-	-	-	-	-	-	-	-	-	19P
Grapsoid crabs	-	-	-	-	-	-	80P	-	-	-	-	-	-	-
Lybia tessalata	-	-	-	-	-	-	-	-	-	-	-	-	-	1P
Crabs, other	20P	P	P	P	P	P	P	120P	P	P	20P	-	-	P
GASTROPODA														
Patelloida sp.	-	-	-	20	-	-	-	-	-	-	-	-	-	-
Patella stellaeformis	-	-	1	-	-	-	-	-	-	-	-	-	-	-
*Nerita plicata	50,000	6000	4	-	-	-	-	-	-	-	-	-	-	-
*Cerithium concisum	1100	200	28	20	-	-	-	-	-	-	-	-	-	-
Cerithium obeliscus	-	-	-	20	20	-	-	20	-	1	-	-	-	-
*Cerithium columna	-	9000	1420	1000	20	20	-	20	-	-	-	-	-	-
*Nautica sp.	-	3	3	20	0	-	-	-	-	-	-	-	-	-
*Monetaria moneta	6	18	30	50	140	160	40	180	100	80	5	-	-	-
*Ranularia muricina	-	10	4	4	-	-	60	20	40	40	-	-	-	-
*Cymathium chlorostomum	-	-	1	1	20	-	-	-	-	-	4	-	-	-
Bursa bufonia	-	-	-	-	-	-	-	-	-	40	4	60	-	-

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Gyroscala perplexa	-	-	-	20	-	-	-	-	-	-	-	-	-	-
*Thais hippocastanum	4	7	16	20	3	2	-	-	-	-	-	-	-	-
Vasum ceramicum	-	-	-	-	-	-	-	-	-	-	20	2	2P	-
*Mitra litterata	250	85	49	500	160	40	50	20	20	40	80	100	-	2P
*Mitra virgata	5	-	-	-	-	-	80	-	-	40	-	-	-	-
*Engina mendicaraia	150	8	21	70	40	4	-	-	-	-	-	-	-	-
*Drupa grossularia	-	2	1	-	-	-	-	-	-	-	-	20	-	-
Drupa ricina	-	-	1	-	-	-	-	-	-	-	-	-	-	-
*Morula granulata	52	30	6	6	1	-	-	-	-	-	20	40	-	-
*Morula fiscella	150	-	-	20	-	-	-	-	-	-	-	-	-	-
*Conus hebraeus & C. spondylus	22	81	100	500	140	60	60	120	-	2	1	-	-	-
*Conus miliaris	-	2	8	70	1	-	1	20	20	-	1	-	-	-
Conus flavidus	-	-	-	-	-	20	-	20	-	-	1	-	1P	-
Conus sp.	1	-	-	-	-	-	-	60	-	-	-	-	-	-
Cythara sp.	-	-	-	200	20	280	-	-	-	-	-	-	-	-
*Torinia varigata	1	1	2	20	20	20	-	-	-	-	-	-	-	-
Vermitidae	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Nudibranch	-	-	1	-	1	-	-	-	-	P	-	-	-	-

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PELECYPODA														
*Barbatia tenella	1	-	5	P	20	40	360	390	1400	720	840	260	1P	-
Volsella auriculata	-	-	-	40	-	-	-	-	-	-	-	-	-	-
*Isognomon perna	3	2	3	-	20	40	-	-	20	60	-	-	-	-
*Gafrarium pectinata	-	-	2	-	-	-	-	-	-	-	-	-	-	-
ECHINODERMATA														
Tripneustes gratilla	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Echinometra mathaei	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Diadema paucispinus	-	-	-	-	-	-	-	P	-	-	-	-	-	-
Distichopis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	P
Ophiocoma brevipes	-	-	-	-	-	-	-	-	-	-	1	-	-	P
Other brittle stars	125P	2	8	-	1P	-	2P	-	-	-	-	120P	P	-
Holothuria atra	-	P	1	1	-	-	-	1	-	1	1	-	-	-
Actinopyga mauritana	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Other Holothurians	-	-	-	-	-	-	-	-	-	20	-	-	-	-
CHORDATA														
Ptychodera sp.	1	P	P	-	20P	-	-	-	-	-	-	-	-	-

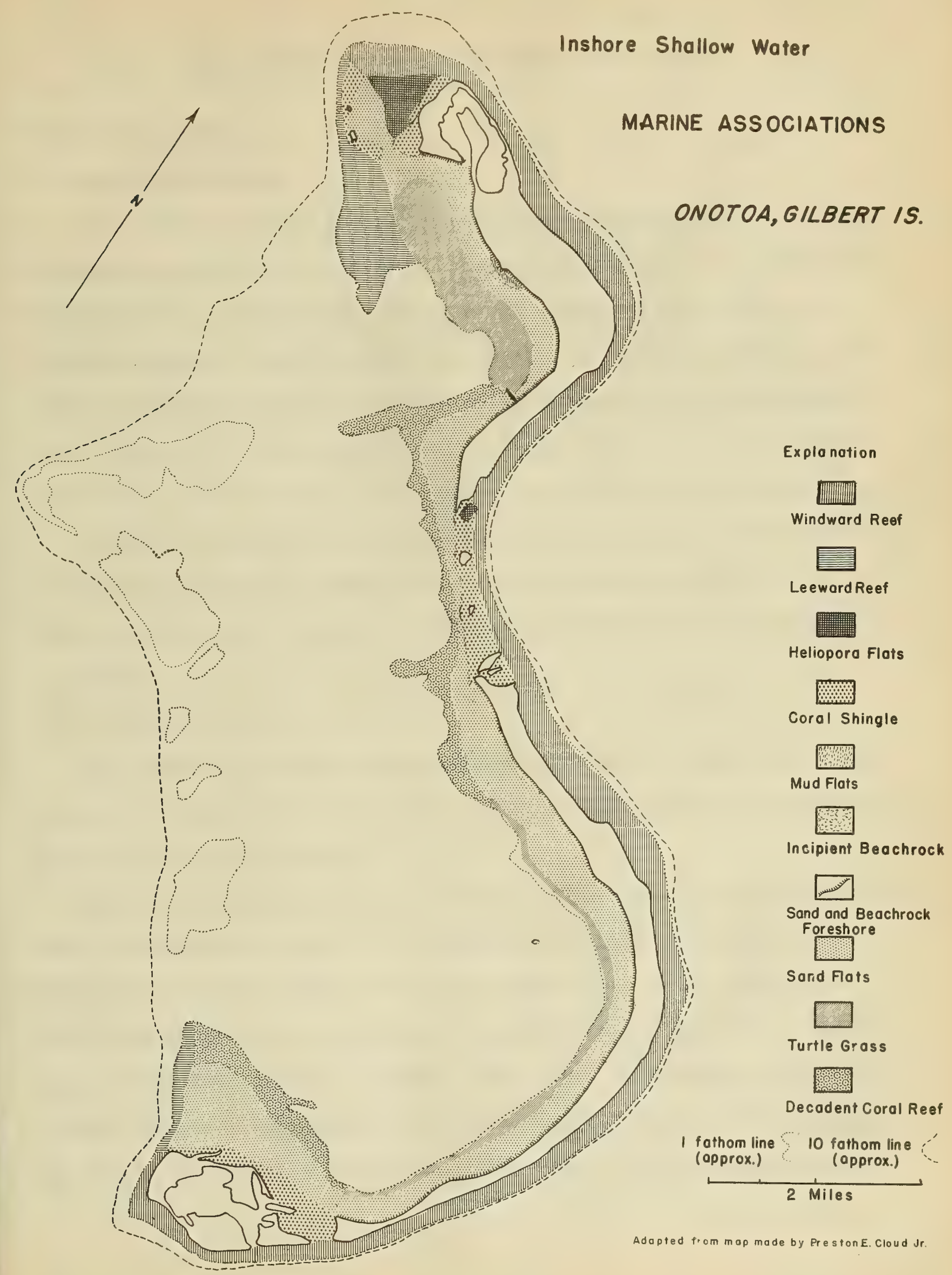
Coralline ridge.

The topographical features of this ridge are described above. Unfortunately tides and waves did not permit an examination, neither quantitative nor qualitative, of the fauna of this zone. The relatively smooth surface of the coralline algae did not offer any protection for animal life; the shifting rocks at the bottom of the surge channels offered less. However, reaching into the mass of the coralline algae were numerous openings, and within the heads were chambers in which many animals lived. In this habitat were found such animals as Echinometra mathei, Heterocentrosus sp., and several species of xanthid crabs.

Reef Shelf.

This area, lying beyond the outer edge of the coralline ridge, was estimated to be about 300 feet wide, from 8-10 feet deep at the coralline ridge to about 30 feet deep where the bottom begins to drop away abruptly. In this area no invertebrates other than corals were observed, and no facilities were available to transport heads of coral to shore for further examination; however, numerous holes were noted in the coral floor where crustaceans, worms and other forms could have lived.

The coral on the shelf was roughly zoned, with the dominant species in the shallower water near the coralline ridge being Pocillopora meandrina, and in the deeper water of the middle and outer shelf, species of Acropora. In the middle and outer portions of the shelf massive heads of Porites lobata were conspicuous. Among the other corals found in this area were all of those reported from the back-ridge trough and some small specimens of Stylaster growing on the undersides of coral heads in twenty feet or more of water. Large areas of the bottom were covered with dead, loose fronds of Acropora.


Inshore Shallow Water
MARINE ASSOCIATIONS
ONOTOA, GILBERT IS.
N
Explanation
Windward Reef
Leeward Reef
Heliopora Flats
Coral Shingle
Mud Flats
Incipient Beachrock
Sand and Beachrock Foreshore
Sand Flats
Turtle Grass
Decadent Coral Reef
1 fathom line (approx.)
10 fathom line (approx.)
2 Miles
Adapted from map made by Preston E. Cloud Jr.
A. H. Banner

SHALLOW WATER LAGOON REGIONS AND ADJACENT AREAS

AREAS NOT IN LAGOON.

I. Leeward Island Reef.

This area lies to the lee of the ends of the islands, west and northwest of Tabaurorae and its northern reef. The regions faunistically approach the windward reef but on them there is not a well-developed reef flat and no backridge trough or coralline ridge whatsoever, but instead changes at places quite abruptly into conditions similar to the reef shelf off the windward reef. In water of moderate depths -- two to five feet -- the major elements of the fauna are the same as the backridge trough on the windward reef.

The major exception to these generalities lies in the region northward of the Heliopora flats off Anteuma; here, the conditions are similar to the area within the reef to the west of Abenecnec Island (to be described by Dr. Cloud).

II. Heliopora Flats.

The areas designated as Heliopora Flats are found in a protected region behind the windward reef at the south end of the north island and northwest of the tip of the north island.

The southern Heliopora flat consists of an extensive tide pool about 800 feet in diameter, protected on the oceanside by a coarse coralline boulder ridge, and by elevated sand and boulder covered reefs on the other sides. The bottom of the pool is estimated to be about the 0.0 tidal level, and the water stands about twelve to eighteen inches deep. The bottom is sand. The dominant animal is _Heliopora_, with one head about every square yard; _Porites sp._ is perhaps a tenth as plentiful. Other corals, all infrequent, include

Orbicella, Pocillopora, Leptoria. On the exposed sand bottom no animals except Holothuria atra are conspicuous. Other invertebrates are found in two habitats.

A. Under coral heads. Here are found stomatopods (Pseudosquilla ciliata), Tethys, two species of tunicates, four species of holothuroids, *Thais hippocastanum, and several species of brachyuran crabs.

B. In coral heads. Here the dominant forms are crangonid shrimps and small xanthid crabs. Encrusting sponges of various types are common; black colonial tunicates are plentiful; one head only showed numerous small sea anemones. Annelid worms, both Errantia and Sedentaria, are moderately common. Several species of clams, including *Isognomon sp. and *Barbatia tenella, are found between the inner branches of the coral.

The northern Heliopora flat is faunistically similar to the southern, with the same population. However, it shows the transition, on its inner side, between a typical Heliopora flat as described above with infrequent heads of Heliopora reaching from the sand bottom, through a condition where the Heliopora is growing thickly and the top ends were being consolidated by coralline algae, to a consolidated condition like that described in section A-8 of the windward reef. In the labyrinthian passages below the surface consolidation are numerous small fish. On the outer edge these flats gradually change in a moderately deep water coral association with passages between the coral six or more feet deep.

III. Shingle Flats.

These areas of shingle -- flattened and waveworn coral rocks lie in regions where the waves and the currents are strong enough to sweep away the sand. These conditions are found in the passes between the islands, as in the three passes between North Island and South Island, and the two passes west of South Island. The size of the rocks varies with location, being large

where there is an unbroken sweep of the water, as between the windward side of the Abenecnec passes, and gradually changing into fine gravel on the more protected extensions of the current, as to the west end of the southern tip of North Island, which in turn is replaced by the fine sand characteristic of the lagoon. All shingle areas inspected were above the 0.0 tidal zone, and in places extended up to the edge of the terrestrial flora. In some portions of the passes there were developed broad shallow tidal pools, with a bottom of finer rocks or sand.

Without exception these actual pass areas were found to be devoid of larger animals; even the tidal pools appeared lifeless. However, where there was slight protection either from islands or from bars, there was a feeble fauna developed, with some xanthid crabs, a few sponges and heads of _Porites_ in the tidal pools. In the fine gravel zones, transitional between the shingle and the lagoon sand, some life was found in the levels near the zero tide zone. Burrowing into the dead coral reef under these areas were found sipunculids and annelids; in the small shallow tidal pools were found occasional brittle stars, solitary zooanthids and small crabs under the scattered loose boulders.

LAGOON AREAS

IV. Sand Foreshore.

Along the lagoon side of the island the foreshore, from about the two foot tidal level up alternates between fine sand and consolidated beach rock with more areas of beachrock off the northern island and more sand off the southern. Only near the tips of the islands and around smaller islands like Anteuma and Abenecnec are these two characteristic beach formations replaced by coral shingle. The sand foreshore is devoid of life except for occasional ghost crabs _Ocypode ceratophthalma_ the same species that is found much more

plentifully on the windward sand beach.

V. Beach-rock Foreshore.

Alternating with the sand foreshore are areas where the elevated beach-rock of the island's base is exposed by wave action. This slab is eroded on the top surface into the typical cupped pattern, and often is undercut along the lower edge by wave action and possibly solution by fresh water from the island lens. At places, especially in the lower tidal zones, the undercutting has proceeded far enough so that slabs up to several feet or more long have broken off from the base rock and lie free on the substrate of either beach-rock or of sand.

Animal communities in this habitat when the tide is out are subjected to dessication and heat, to rain and especially to the flowing fresh water, common all along the shore; when the tide is in, to moderate wave action (except, possibly during periods of storms from the west when the wave action would be vigorous).

The rocks can be subdivided into four associations:

A. The higher beach-rock area. This is above about the 2.5 foot tidal zone and is almost devoid of life except for *Nerita plicata and Grapsus grapsus, neither as common as on the similar rocks on the windward side of the island.

B. Lower beach-rock area, rocks lying on solid substrate or undercut solid rock. These rocks lie between the 0.0 and 2.5 tidal zones. In them are found burrowing sipunculid worms; near the edges of the rocks are numerous Holothuria atra and less numerous Holothuria monocaria, some colonies of colonial tunicates and some sponges; under them are numerous crabs of at least four species, four or more species of crangonid shrimps, very few hermit crabs, and no worms.

C. Lower beach-rock, rocks lying on sand. These are in the same zone as B above, but lie with the base imbedded in the sand. About their edges is the common Holothuria atra and clusters of zooanthids; in burrows under them in the sand are numerous large worms of the genus Eurythoe and three species of crangonid shrimps.

D. Lower beach-rock, suspended rocks. These, lying with one end on other rocks, leave a large surface underneath open to free circulation of water or air, and protection from the sun and rain. On this surface, hanging down, are hydroid colonies in profusion, and some colonial tunicates, a few sponges.

VI Mud Flats.

In a short narrow area along the middle of the North Island, below the foreshore and behind the incipient beach-rock (VII) there is a mud flat. The height of the mud flat is slightly above the zero tide level. The mud is soft, so that a person walking over it would sink between ankle and knee-deep; slippery with little admixture of sand, and rich in organic matter whose decomposition gives it the characteristic odor of hydrogen sulfide.

In this mud flat proper is only one species visible, the brilliantly colored fiddler crab, living in burrows. In areas transitional between the mud flat and the sand are found some burrows of stomatopods. There were no traces of annelid burrows or of other macroscopic life.

VII Incipient Beach-rock

A small area off middle of the northern island, bounded inshore by the mudflats (VI) and off shore and at the ends by sand flats or turtle grass (VIII and IX), is composed of beach-rock in the process of formation, according to Dr. Cloud. The rock is as firm, or almost as firm as the typical elevated beach rock (V) but its surface, near the zero tide zone, was roughly eroded like the more exposed rock (IV-A).

In protected areas in the rock, as in deeper cusps, in fissures and under the occasional loose rocks are the following snails: *Thais hippocastanum; *Mitra virgata and *M. litterata; *Cymathium chlorostomum and *Conus hebraeus. Under the rocks are numerous hermit crabs. Burrowing into the rock were sipunculoid worms and sea anemones were found in protected locations where they were living in shallow pits that precisely fitted the basal portions of their columns. In shallow but rather long burrows that they have either excavated or taken are the large red-eyed crabs and fiddler crabs; at the entrance of these burrows were vast numbers of Collembola.

VIII Sand Flats.

The most extensive habitat in the lagoon is the sand flat. These flats run from the inshore beach along the three major islands extending as a broad, almost level, flat from the inshore beach outwards for several hundred feet wide to a half mile or more. On the outward edge they either continue as the sand bottom of the lagoon or are covered by turtle grass (IX), or are demarked by a decadent coral reef (X). The portions of this area described below run from about two feet above to several feet below the zero tidal zone. The sand varies from less than an inch thick, covering old coral reef, to at least several feet thick.

The fauna of this zone varies with the depth in the tidal zone, the fineness of sand particles, the amount of wave action, and with the depth of the sand. The differences in the fauna are not well demarked and most often are quantitative rather than qualitative -- the same species present in most areas, but varying in relative abundance. Of course, with the difference in depth the fauna changed markedly; for example, in the highest portion here considered (some tidal pools in the middle tidal zone off Anteuma), the only elements of

the fauna left were the Enteropneustan, Ptychodera, and on the other hand, below the -1.0 tide level solitary heads of coral would reach up above the surrounding sand.

These solitary heads of coral in this area, like those in the Turtle grass area, constituted microenvironments markedly different from the surrounding sand. For that reason they are considered as a separate subdivision below.

A. Sand area proper, fauna:

Porifera: Purple sponge, black sponge (two kinds), orange sponge.

Coelenterata: Zooanthids (corals considered below).

Annelida: Tubeworms with leathery tubes and with sand tubes; two species of Errantia; small and giant sipunculids.

Crustacea: Lysiosquilla maculata; Callianassids, Calappa sp.

Mollusca: (Note: remarkably few traces of living mollusca were found, although dead shells were seen in some areas; this may be attributed to the fact that most of the sand flat molluscs are esteemed as food by the Gilbertese.) Clams, various species including *Gafrarium pectinata, *Tellina crassiplicata, *Tellina sp., *Nautica sp., various species of Mitra, Terebra, Cymathium, Trochus.

Echinodermata:

Holothuria atra (extremely common in some areas, counted at 5-15 per square yard).

Chordata:

Ptychodera sp.

B. Isolated coral heads, fauna:

Porifera: same as above.

Coelenterata: Porites sp. (dominant); Pocillopora damicornis; Acropora servicornis; Orbicella; other corals in lesser numbers.

Pennaria.

Annelida: Tube worms in limy tubes; sipunculids

Crustacea: Crangonids, various species; brachyuran crabs.

Mollusca: Cyprea erosa, *Monetaria moneta, *Barbatia amygdalumtostum.

Chordata: Colonial tunicates.

IX. Turtle Grass

Large areas in the northern part of the lagoon and portions of the southern lagoon are dominated by Turtle Grass (Thallasia sp.) which extends over the sand bottom from water about at the zero tide line or a little above to six or ten feet below the surface. The Turtle Grass, which makes a dense stand like the northern eel-grass (Zostera), seldom grows over a foot or more high; its creeping rhizomes make a dense interwoven mat in the sand substrate. In the southern portion of the lagoon less area is adaptable to the growth of the plant, and in general it is limited to a relatively narrow zone near the shore of the island; in the middle of the lagoon, off the passes between North and South Island and the adjacent areas, and off Tabuarorae and the southwesternmost portion of the lagoon there is no Turtle Grass whatsoever.

The Turtle Grass proper is relatively devoid of invertebrate life. On the fronds of the grass are found black colonial tunicates and occasional sponges of several types; about the bases of the grass are more sponges of the same type and, most abundant in many areas, a papillose green-black holothurian. It was impossible, once digging was started, to dig out the

few burrowing animals detected because of the clouds of fine silt that rendered underwater vision impossible. The burrowing animals, however, are few in number and appeared to be limited to a small squillid (Lysiosquilla) and some burrowing worms.

In the deeper portions of the Turtle Grass beds, especially in the area off the northern island, there appear solitary and separated coral masses, like islands in a sea of grass. These isolated masses are rich in life, both fish and invertebrate. They evidently are made up primarily of Porites, but they are covered in a large extent by other corals like Acropora, Pocillopora, Orbicella, etc. The invertebrate fauna is in general similar to the fauna of coral heads in the sand beach area (VIII-B).

X. Decadent Coral Reef.

In many areas the sand flats grade gradually into a region of dead coral reefs that lie between + 1.0 and - 1.0 tidal level. These areas appear to be those where the wave action and current action is stronger, sweeping the veneer of sand from the harder substrate. They are found to the southeast of Anteuma; off the southern portion of the North Island and the northern portion of the South Island and the passages between; and they are extensively developed off Tabuarorae and in the southwestern portions of the lagoon.

The decadent to dead coral reefs present a variety of habitats for invertebrates: on the hard coral there are places of attachment, protected and unprotected, for sessile forms; in naturally occurring spaces and in burrows in the coral there are places for the smaller invertebrates to hide; in the areas between the heads of coral, either broken off as the reef was growing or subsequently eroded from the reef surface are pockets of sand and gravel to accommodate burrowing forms; these pockets, some of them many feet

long, retain water when the tide is out and provide a tidal pool for the protection of its inhabitants. For this reason the fauna of the area is more diverse than any other area of the lagoon; however, with few exceptions, no elements of the fauna are exceedingly common:

Porifera:	Yellow to red encrusting sponges, several species	Moderately common
	Black, rounded sponge	Uncommon
	Orange upstanding sponge	Uncommon
Coelenterata:		
	Pennaria	Common on undersides of coral overhangs.
	Porites, living	Uncommon
	Pocillopora damicornis	Uncommon
Annelida:		
	Worms in limy tubes, two species	Uncommon
	Burrowing Errantia, 1 specimen	Uncommon
	Sipunculus sp.	Common
Crustacea:		
	Crangon, and other genera	Uncommon
	Brachyuran crabs (other than Portunids)	Uncommon
	(Portunids)	(Moderately common)
	Hermit Crabs	Rare
Gastropoda:		
	*Conus hebraeus	Uncommon
	Conus flavidus	Rare
	*Monetaria moneta	Moderately common
	*Nautica sp.	Rare
	*Mitra virgata	Rare
	Nudibranch	Rare

Pelecypoda:

*Barbatia amygdalumtostum	Uncommon
*Isognomon perna	Common
*Pinctada vulgaris	Common
*Tellina sp.	Rare
*Tellina crassiplicata	Rare

Echinodermata:

Brittle Stars (as in A-2 windward reef)	Common
Linkia sp.	Rare
Holothuria atra	Abundant in tide-pools at inner edge of area (60 in one pool of about 60 square feet); otherwise rare.
Papillose sea cucumber (as in IX above)	Rare

Chordata:

Ptychodera	Rare
Encrusting compound tunicate, three species	Rare to common, according to the species.

III

GILBERTESE UTILIZATION OF INVERTEBRATES

One of the important phases of a study of a native peoples is the study of the food resources available to the people, and of their utilization of these resources. This is especially true of the inhabitants of a coral atoll, where the food resources at best are somewhat limited, and where, on a small dry and overpopulated atoll like Onotoa, these resources may be the deciding factor in social structure and even of life and death.

On Onotoa the population had available three sources of food; the conventional land produce, plant and animal which obviously was inadequate to support the island's population, especially in times of drought; the marine fisheries, apparently the chief source of protein in the native diets and one of the main sources of calories; and finally, the marine invertebrates, which appeared to be at best merely a supplementary source of food, gathered primarily either when fortuitous occasions arose, like low tides at night for the collection of lobsters, or to serve as mere variations in the usual diet of coconut-pandanus-fish.

However, this study will give some indication of the extent that the Onotoans are utilizing most of the available resources as food.

Methods and Limitations of the Study:

This study was carried on to large part when I was immobilized by blood-poisoning. A native assistant was assigned to help me when he was not busy with other jobs; he was willing and cooperative, but the study was inhibited by his most imperfect English and my total lack of Gilbertese; at times an interpreter was used to bridge the gap.

The study, in its original phases, consisted of looking at pictures in illustrated books of marine life. Later, upon finding that that system was inaccurate because of the inability of natives to interpret correctly the illustrations, all information was gathered by showing the natives actual specimens, specimens that were either collected for us by our native assistants or by ourselves.

The study has three major limitations and sources of inaccuracies. First is the probability that we were unable to find all of the foods of the people because we had neither illustrations nor specimens of them, and our informants did not discuss them because of the language limitations. Second because of their "willingness to please" the natives included animals that possibly were not eaten, or that were eaten only under extreme famine conditions. To remove this possibility several natives were checked, one against another, in as many instances as possible. Third is that not all individuals or family groups utilize the invertebrate foods as much as others -- like in our own society some families eat crabs but others would not consider them. Perhaps my informants were not among those who knew and utilized all of the foods found on the reefs and shores of Onotoa. I did observe on some of the food species that there was no agreement as to the native name; for example, I received three native names for the snail Quimalea pomum. This would seem to indicate that it was not a common article of food.

Systematic Account

Scientific Name Native Name	Notes
1. Coelenterata-Scyphozoa (Carybdea alata Reynaud) Te Baitari	These large (10-12") scyphomedusae occurred at a moderate tide slightly before the full of the moon; reportedly

they occurred at similar phases of the moon throughout the year. They are gathered on the windward reef by wading women and children who either put them in baskets or string them on pandanus fibers. In preparation the outer layers of jelly are stripped off, the oral and aboral ends removed and only the remaining material -- the muscular coat of the gastro-vascular cavity is saved. The cleaned material is thus 6-8 inches long, $1\frac{1}{2}$ inches broad and about 1/8 inch thick. It is reported that this is boiled to form a rather sticky "soup".

Annelida-Sipunculoidea

2. Sipunculus indicus Peters

Te Ibo

These are found burrowing in sand flats of the lagoon. They are one to two feet long and the diameter of a man's little finger. When the native, usually a man, finds a hole and casting made by the worm he probes the sand behind it with a flexible and sharpened young root of a pandanus; this, when hitting the vertical portion of the worm burrow follows down the tube. When the worm is touched

by the tip of the probe, it is thrust with vigour and penetrates with the introvert into the anterior body pocket, securely holding the worm. The worm is then dug from the tube. The probe is jerked out, rupturing the anterior body wall of the worm. Then the worm is seized by the back end and snapped like a whip, completely eviscerating it and leaving nothing but the thick muscular coat. This is washed and eaten raw, cooked by boiling or dried for future use.

Arthropoda, Crustacea-Stomatopoda

3. <u>Lysiosquilla maculata</u>

Te Waro

This large stomatopod (about 1 foot long) is found only burrowed in the sand in the lagoon. It is caught by both men and women by placing a spear in the sand so that it is in line with the hole; a piece of fish is placed at the entrance of the burrow as a lure, a noise is made to attract its attention, and as the stomatopod comes to the mouth of the burrow to strike the bait, the spear is thrust home. The animal is cooked and all except the viscera under

the carapace is eaten.

4. <u>Pseudosquilla ciliata</u> <u>(and other species)</u>

Te Waro (as above)

All smaller stomatopods when captured are eaten; they run from one to four inches long. The principal source of these stomatopods is under rocks on the windward reef flat, where they are gathered by hand or by small scoop nets together with shrimps, etc. They are gathered principally by women. Method of preparation as in 3 above.

Decapoda

5. <u>Crangon</u> <u>strenuus</u> (Dana)

Teniwarowaro

(Note: this Gilbertese name evidently includes other genera and species of chelate shrimp and lobster-like crustaceans but the only form observed was <u>Crangon</u> <u>strenuus</u>). These range in size from one inch to fourteen inches long and are caught by all members of the family near the back-ridge trough of the windward reef in small nets when torch-fishing. They are boiled and both the cephalothorax and abdomen are eaten.

6. <u>Panulirus</u> <u>pencillatus</u> (Oliver)

Te Ura

This lobster runs from six to eighteen inches long. It is caught along the windward reef by men and women either during the day when the tide is out or

over the reef surface at night, when torch fishing. Dip nets are used for its capture. It is boiled and the abdomen, portions of the cephalothorax, and legs are eaten.

7. Parabaccus antarcticus (Lund) Te Mnawa	The sand lobster reaches the length of nine inches; it is caught, prepared and eaten in the same way as in 6.
8. Birgus latro Te Aii	These coconut crabs are entirely terrestrial and are found by day in burrows. They are dug out only by men. When boiled the abdomen and legs are eaten.
9. Geocaroides sp. Te Manai	These large land crabs are found only on the North ends of both major islands of Onotoa. They are caught by men and women at night by torch light in the middle of the island. They are boiled and eaten like other crabs (see below).
10. (Terrestrial Hermit Crabs) Te Makauro	These are small terrestrial hermit crabs that live in the shells of Turbo, etc. They are caught either by day or by night, the latter time by torch light. Only children were observed gathering them. They are boiled and the abdomen alone is eaten.

11. Calappa hepatica (L.)
Tennonno

These sand crabs reach the breadth of about 3". They are captured in the sand of the lagoon when the tide is out by feeling for them under the sand with the hands or feet. Everyone helps in their capture. They are boiled and the legs alone are eaten.

12. Charybdis erythrodactyla (Lamark)
Tentabarereki

These crabs are six to eight inches broad across the carapace and found both on the windward reef and in the lagoon. They are gathered by anyone finding them and boiled; the legs and the ventral portion of the cephalothorax is eaten.

13. Carpilius maculatus (L.)
Te Iba Taburimai

These crabs are found only on the windward reef when the tide is out by day or at night by torchfishing; only adults catch them, either by nets or by hand. They are boiled and eaten as above.

14. (Unidentified crab)
Te Nikarewerewe

These crabs are about 6-7" across the carapace, and their habitat, mode of capture and preparation are the same as 13.

15. (Red-eyed crab)
Tentababa

These crabs are found high in the intertidal zone on both windward and leeward beaches, underneath beachrock;

they reach the carapace breadth of about 3 inches. Anyone may catch them, and they are gathered by hand and prepared in the same fashion as above.

16. Ocypode ceratophthalma (Pallas) — These "ghost crabs" are found high on the sand beaches on both shores of the islands where they live in burrows; they reach the breadth of 3". Anyone may capture them, either by digging by day or by torching at night with a net. They are boiled and portions attached to the ventral half of the body are eaten.

Te Kauki

17. Zozymus aeneus L. — These crabs are found at night on the windward reef in torch fishing; they are reputedly extremely poisonous in all parts of the body, causing rapid death when eaten. They are never used as food.

Te Kukua

Mollusca, Gastropoda

18. Trochus, all species — These are found along the windward reef; they are gathered by all members of the family, boiled in the shell and the meat is pulled from the shell for eating.

Te Baraitoa

19. Turbo, all species
Te Nimatanin

These are found along the windward reef where they are gathered by all members of the family; they may be prepared or the shell may be broken and the snail eaten raw.

20. Cerithium, all species
Te Bukikakang

These are found in the sand of the lagoon when the tide is out; they are gathered by everyone. The snail is cooked in the shell and the meat removed after cooking; the shells are used for ornamental bands on dancing belts, etc.

23. Lambis, all species
Teneang

These snails are found on coral in the outer portions of the lagoon, in waist deep or deeper water. Only the men gather the snail; it may be eaten raw after breaking the shell or it may be boiled intact with the meat subsequently removed.

24. Nautica sp.
Te Tumara

These are found a few inches under the sand in the lagoon; they are caught by everyone, boiled in the shell and the meat subsequently removed.

25. Monetaria moneta (L.)
Te Burerewa

These are found in both on windward reef and in the lagoon; they are gathered by everyone. The snails are

		used only for shell ornaments; they are first boiled and then buried in the sand for two to four weeks, and finally washed in fresh water.
26.	<u>Cyprea</u>, various species Te Kabaua	These also are not eaten, but gathered to be used as shell ornaments. The larger species of cowries are not used at all. Method of preparation is the same as <u>Monetaria moneta</u> (L.) (25).
27.	<u>Amphiperas ovum</u> Te Bure	These shells are not found on Onotoa, but are imported from Abemama to be used as ornaments for the bow and stern of the outrigger canoes, and for decorations in the Maneabas.
28.	<u>Nerita plicata</u> Te Kaban	These snails are found high on the rocks on the windward beaches and to lesser extent on the lagoon beaches; they are gathered by everyone and cooked in the shell.
29.	<u>Cymathium</u> sp. Te Wiaau	These are found on the lagoon beaches at low tide only near Aiaki (the middle of South Island); they are gathered by everyone and boiled in the shell.
30.	<u>Bursa bufonia</u> Te Kamanging	These are found only on the windward reef flat, where they are gathered by everyone; they are boiled in the shell before eating.

31.	<u>Charonia tritonis</u> Te Tauu	This large conch or triton is found along the outer edge of the lagoon on coral in waist deep or deeper water; it is gathered only by men. It is considered poisonous and not eaten; however, the shell is used as a trumpet to announce meetings in the community hall, and the shell, hung upside down, is used as a flask to store coconut oil (the oil is poured out of the syphon, from which it emerges in a small and easily controlled stream).
32.	<u>Tonna perdix</u> Te Tau	This snail is found in the lagoon in water two fathoms or more deep, on coral; it is gathered only by men. Before eating, the animal is boiled in the shell (one old man informed me it was the young of the conch (31) and had the same name).
33.	<u>Quimalea pomum</u> Te Makauro-n Tari	This snail is found in the same habitat and prepared the same way as Tonna perdix (32).
34.	<u>Vasum ceramicum</u> <u>Thais hippocastanum</u> (L.) <u>Morula granulata Duclos</u> Te Nimakaka	These species are all found on the windward reef flat, where they may be gathered by men, women or children; they are cooked in the shell. All are known by the same name.

35.	Conus, all species Te Nouo	These species are found variously on the ocean or lagoon side of the island in shallow or deep water; primarily women and children gather them on the windward reef, while only men gather them in the deeper water of the lagoon. While Conus striatus, one of the poison cones, is among those gathered, the Gilbertese seem to have no knowledge of its "sting". All are boiled before eating, and then the shell is broken to withdraw the meat. Another informant called them "Te Nuo Nuo".
36.	Pollia undosa Te Wikakang	These snails are found only on the windward reef flat and gathered by everyone. They are cooked and the meat is then pulled from the shell.
37.	Mitra, all species Terebra, all species Te Kabinea	These snails are found only buried one to two inches deep in the sand of the lagoon when the tide goes out; they are gathered by all members of the family and boiled in the shell. Both genera have similar habitats and bear the same Gilbertese name.
38.	Melampus, all species Te Kokoti	These species are found only high on rocky beaches on the northwestern and

southwestern islands, where they are gathered only by women and children; the snails are not eaten but the shells are used as ornaments on articles of clothing.

39. (Nudibranch) Nei Kamanging — This four-inch nudibranch is found on the middle section of the windward reef under rocks; it is gathered by anyone finding it; before being eaten it is boiled for two or three hours.

40. (Nudibranch) Neireurekia — This is essentially the same as the nudibranch above (39), except before being cooked the visceral mass is removed.

Mollusca; Pelecypoda

41. Pinna atropurpurea Te Raun — Found only in southern part of lagoon, two fathoms or more deep, partially buried in sand. It is gathered by men only, and boiled before being eaten.

42. Streptopinna saccata Te Bere — This "clam" is found along lagoon shores in sand, one foot or more deep. Evidently it is not used for food or ornament.

43. Pinctada margunifera — The pearl oyster is found only on the sand bottom of the southwestern lagoon in three or more fathoms of water. It

is gathered by men only. The meat is removed from the shell before it is boiled. Some pearls are found and the shell can be sold but there is no established pearling trade on Onotoa. The shell is used also by the men for ornaments on belts, for earrings and for canoe decorations.

44. Hippopus hippopus

Te Nei Toro - small individuals

Te Aubuna - large individuals

This giant clam is found on both lagoon and ocean reefs from three feet deep to about two fathoms. All sizes, from two or three inch specimens to those about three feet across, are gathered by men for eating. At times they are eaten raw. When fresh, their meat is boiled with water or coconut milk; they may also be dried with salt and kept several months. The large shells are often used as wash basins. Some families make small holding pens of coral along the beach in front of their houses and keep small specimens alive until they grow larger, or until the family is ready to eat them. One family had a pen about four feet square that held ten clams ranging in size from three to twelve inches across.

45. *Tridacna cumingi*
Tridacna elongata
Te Were

These are the same as *Hippopus* above (44) excepting for their smaller size -- up to nine inches across in lagoon, three inches across along the ocean.

46. *Tridacna squamosa*
Te Were Makai

These are the same as *Hippopus* above (44); size up to about fourteen inches across.

47. *Cardium* sp.
Te Tuai or
Te Taerake

These cockles are found in the lagoon only slightly under the surface of the sand, in intertidal zone. They are gathered by everyone; the clam is boiled for food and the shell is used as a coconut meat scraper to make baby food.

48. *Cardium* (*Trachycardium*) *flavum*
Te Nikarikiriki

These cockles are found near the surface of the sand in the intertidal zone along the southern island only. They are gathered by everyone and boiled in the shell before being eaten.

49. *Cafraum tumidum*
Venus clathrata
Te Koikoinanti

These are both found in outer lagoon on coral and not in sand, in about one fathom of water. They are gathered by both men and women diving from canoes. They are removed from the shell before boiling. Both species are referred to by the same name.

50. Pitar (Agriopoma) japonica | Mesodesma striata | Te Katura

Both of these clams are found along islands buried one to two inches deep in the sand high in the intertidal zone. They are gathered by everyone and boiled in their shells before eating.

51. Protothraca staminea | Te Koumara

This clam is found low in the intertidal zone along the lagoon only near the end islands buried up to six inches deep in the sand. It is gathered by women and children and may be either eaten raw or boiled in the shells.

52. Tellina crassiplicata | Te Nikatona

This clam is found buried eight to twelve inches deep in sand in lower intertidal zone off the south and north island and off the south island. It is reported to be about "fished out". It is dug the year around by anyone. It may be eaten raw, boiled after removing from the shell, or salted and dried.

53. Asaphia dichotoma | Tei Koikoi

This clam is found in lagoon sand in lower intertidal zone buried about one foot deep all along the coast except off the middle of the southern island. It is dug only by women and children; it may be eaten raw or boiled in the shell.

54. Asaphis deflorata — Te Bun

This clam is found only at Abemama Island but not on Onotoa nor any other island; it is found low in intertidal zone in sand of the lagoon. On Abemama it is dug by everyone; it may be eaten raw or bioled and is reportedly of excellent taste. The shells were imported to Onotoa to be used as fishing sinkers.

55. Polypus marmoratus — Te Kika

The octopus is one of the principal invertebrate foods of the people. It is caught on both sides of the island in holes under rocks when the tide is out by spearing with short hocked spears. Men, women and children all capture it. All parts of it are eaten except the ink sac. Several methods of preparation are used with it: It can be pounded on a stone without additional salt until soft, and then either boiled in water or coconut milk for several hours; or it can be salted and dried to be kept for at least several months. Before the dried octopus is eaten, it is washed and boiled.

DISCUSSION

It is remarkable that these people did not use certain supposedly edible animals of their region. For example, careful questioning showed no evidence of the use of sea weeds, of sea urchins (quite common around the islands), and of marine annelids like the palolo worm. All three of these constituted relatively important foods for the peoples of Hawaii and Samoa. In addition several other foods used by other peoples were not used on the islands, like the sea anemones eaten by Samoans; however, no large sea anemones were seen about Onotoa.

Several foods on their list, on the other hand, possibly are not too wide spread in their use; this is especially true of the scyphomedusae, the sipunculids (although these are eaten in the Marshalls) and the supposedly poisonous cone shells.

The lagoon reef is not very productive of the edible molluscs; in all of the field work in the intertidal areas of the lagoon no evidences of living clams or edible snails were seen. While it is likely this condition stemmed from overfishing by the concentrated population, it may actually be the result of low productivity of the Onotoa lagoon reefs.

PART II

INVESTIGATION OF THE ICHTHYOFAUNA OF ONOTOA, GILBERT ISLANDS

Onotoa is a small atoll with a relatively high population density; it is quite dry and subject to extended drought. Few food plants can be grown, and even the coconut crop fails at times. Thus, for the Gilbertese on Onotoa, there is a very great dependence on the sea for food.

The methods of fishing are many and varied and involve men, women, and children alike. Fishing is undertaken largely by the men, however, and centers around the use of the native outrigger canoe.

Lacking suitable trees for dugouts, the outriggers in the Southern Gilbert Islands are constructed from Australian plank lumber obtained from Ocean Island. No metal parts are used, the planks and outriggers being lashed in place with a native cord made from retted coconut husk fiber. The outrigger itself is a solid piece of wood and usually made from driftwood.

Not every man owns a canoe, but nearly every family has one or access to one. In the village of Aiaki there are 370 people and 82 canoes.* Fifty-eight of these are good-sized sailing canoes and can be used for trolling outside of the lagoon.

The fisherman who owns a canoe will usually have the following items of fishing gear: a few fishing lines of various sizes, a small assortment of hooks, leader wire of flexible galvanized type, a large shark hook, one or two handmade lures, a flying fish net, a pointed metal rod with a wooden handle for gaffing large fish, a knife, and swim goggles. Most of the fishermen own a fish spear with rubber sling. Many families have eel traps and small nets for torch fishing. Some have eel snares, fish traps, beach seines, and fine-mesh nets for small fish.

*This information, as well as certain other facts in this report, was supplied by Dr. Ward Goodenough.

A cooperative store is located on the atoll and is supplied infrequently from Tarawa. It usually has hooks and fish line for sale. Normal-sized hooks are quite inexpensive, ranging in price from $\frac{1}{4}$ to $1\frac{1}{2}$ pennies. The large shark hooks, when in stock, cost 2 shillings 6 pence (30¢). Heavy fishing line, of sufficient length for one trolling line, costs 5 shillings.

The Gilbertese can earn very little money; hence they can buy very few of the preferred manufactured items of fishing gear. Copra and various items of native handicraft made from pandanus leaf fiber are the principal sources of income. Each year about 60 men from Onotoa are taken to Ocean Island where they work as laborers and by their standards are well paid. On their return they customarily bring with them such things as wire, old inner tubes, metal rods, pieces of lead, and glass, all of which are important in their making of fishing gear.

There are many different kinds of fishes which serve as food for the Gilbertese, and frequently special methods of fishing are utilized for certain species or groups of species. Usually these methods are standard from fisherman to fisherman, but some individual variation does, of course, exist. In some cases a family or individual may have an efficient mean of catching fish which is kept secret. The description of the various methods as given below represent the standard ways of procuring food fishes on Onotoa.

Trolling: Sailing canoes are used for trolling which may be undertaken in the lagoon, but the usual site is in deep water just outside of the west reef of the atoll, especially the region where there is a large westward projection of this reef. At most anytime, but especially in the morning, one can see numerous sailing canoes trolling back and forth beyond the reef. These canoes may be operated by a single man or by two persons. If there are two persons, they are usually of the same family, as father and son. Women may help their husbands when trolling, but this is not a common occurrence.

Trolling speed is highly variable depending on the wind, but generally no difficulty is had in attaining speeds sufficiently great with these fleet craft. In fact, it would seem that too often the contrary occurs; that is, that good trolling speed is exceeded.

The lures which are used are commonly of three types. A hook may have chicken feathers tied directly to it. Such a lure is used for smaller fish such as the small tuna, Euthynnus yaito. There may be a lure consisting of a piece of metal, usually lead, in which there is a hole through which the leader wire is run. The back part of the metal is notched for the attachment of feathers. The hook is attached to the leader wire and is always single. The third type of lure is made from an elongate, well-polished piece of pearl shell. The hook is attached directly to the piece of shell, and feathers may or may not be added.

The use of whole fish for trolling is a common practice, mullet and flying fish being the usual bait species. Mullets are netted in ponds or close to shore in the lagoon, and flying fishes are taken with dip nets at night. The bait fish is attached to the hook by locating the eye of the hook in the mouth and the barbed end up through the back so it is just exposed on the dorsal surface. The eyes of the fish are then removed, and coconut husk fiber is used to lash through the orbits to the eye of the hook.

Fishes which are taken when trolling at the surface in deep water are: Euthynnus yaito, Acanthocybium solandri, Istiophorus gladius, Elagatis bipinnulatus, Katsuwonus pelamis, Neothunnus macropterus, and at least one other unidentified species of tuna. Swordfishes are occasionally caught. The dolphin, Coryphaena hippurus, is rarely taken. Nearer the reef, species of Caranx and Sphyraena are caught.

When large-sized fishes are hooked, they are gaffed and their heads beaten with a wooden club before being brought into the canoe.

Spearing: Formerly a long wooden spear with a metal point lashed at one end was employed. This was jabbed at fish while swimming underwater. Now, the common method involves a simple elastic sling device and a steel rod of about $\frac{1}{4}$ inch diameter and five or six feet in length. The sling consists of a piece of truck tire inner tube or a section of bicycle inner tube to which a loop of sturdy cloth is tied at one end and a loop of cord at the other. The metal rod has a notch at one end and is sharpened to a point at the other. There is no folding-type barb, but there may be a small oblique cut made in the rod near the point and the section of metal away from the point bent slightly outward. The thumb of the left hand is placed through the loop of cloth and the notch of the spear engaged in the cord. The notched end of the spear is then drawn back with the right hand, bow and arrow fashion, and the spear is guided as it is launched by the thumb and fingers of the left hand. The spear-fisherman wears small goggles which he makes for himself from local wood and glass obtained from Ocean Island. The goggles are tied on behind the head with heavy string. The final item of spearing accouterment is an optional one and consists of a piece of cord on which the fish are strung. The fish are suspended from the back, the cord being tied around the waist. In swimming the frog kick is used and the fish are approached very cautiously, all sharp movements being avoided. A spear can be shot for a horizontal distance greater than 25 feet but is not very effective beyond a distance of 6 feet or so because of reduced accuracy. Spearing is undertaken in both the lagoon and on the sea side. Generally the lagoon is preferred for there is no heavy surf with which to contend. In the lagoon the fisherman usually

sails or paddles his canoe out to a suitable area. It is anchored with a heavy stone or tied directly to a coral knoll. A paddle or piece of buoyant wood is tied to the anchor line below the surface to prevent the line from catching on coral and chafing.

Spearing fish is a very important method of fishing. It is utilized mostly by the younger men, some of whom prefer it to any other means of obtaining fish. Among those fishes most sought are members of the following genera: *Caranx*, *Scarus*, *Lutianus*, *Myripristis*, *Holocentrus*, *Acanthurus* (especially *A. nigricans* and *A. triostegus*), *Ctenochaetus*, *Gymnothorax*, *Cephalopholis*, and *Epinephelus*.

Shark Fishing: Very strong line, wire leader made from smaller strands of wire crudely twisted together, and a large heavy hook comprise the usual tackle for shark fishing. The hook is usually a purchased commercial product, but it may be made by hand from steel rod, in which case there is no barb but the tip of the hook is strongly recurved. Fishing may be engaged in from canoes drifting well out at sea. Whole fish is the usual bait, the favorite being the small tuna, *Euthynnus yaito*, which is caught by trolling immediately prior to the actual fishing for sharks. If the bait fish is alive, it is hooked carefully through the gill openings; if dead it may be tied securely to the hook with coconut husk fiber in a variety of ways. The line is paid out to windward and remains near the surface. Often several heavy shells (*Lambis truncata*) are tied to a second line which is lowered a few feet below the surface and kept in constant motion. The noise of the shells knocking together supposedly attracts sharks. Some fishermen cut fresh fish into fine pieces and disperse this in the water whereupon the much-discussed power of blood to attract sharks is brought into operation. This surface fishing often

results in the taking of large pelagic fishes such as swordfishes, wahoo, and yellowfin tuna, as well as sharks.

More commonly shark fishing is undertaken over shallow reef areas with a weighted line. Whole fish or cut fish is the usual bait. The sharks taken in reef areas are smaller species, generally, such as the white tip and the black tip.

The flesh of the shark is highly esteemed by the Gilbertese, many of whom actually prefer it to tuna and other fish. It is usually prepared by slicing into sections and roasting in a pit in the ground. Sometimes the flesh is salted and dried in the sun and ultimately eaten without cooking. Still other times it is boiled in sea water.

Night Fishing for Flying Fish: The sailing canoe and at least two persons are required in fishing for flying fish. If there are but two persons, one holds coconut frond torches while the other steers the vessel and works a dip net. Fishing is done outside the reef while moving at ordinary sailing speed. There are usually about eight or ten torches at hand, made from dried coconut leaves lashed in bundles about seven feet long. The first torch is lighted with matches or by striking flint and steel over dried coconut husk. Each subsequent torch is lighted from the previous one just as the latter is about to burn out. The helmsman (and fisherman) generally wears a woven coconut hat to shade his eyes from the torch light. His dip net is elliptical in shape, about two feet in its greatest diameter. The wooden handle is at least twelve feet in length.

The flying fish are attracted to the torch light and skitter about the canoe, some striking the side of it quite resoundingly. The fish are usually caught at the surface but occasionally are picked right out the air by an alert fisherman. When the fish are on the surface the net is dropped directly over them instead of scooping from the side. Usually the netting

operation takes place on the leeward side of the canoe (the side without the outrigger), but the more skillful fishermen extend their range to the water to the stern and the windward side aft of the outrigger.

The only flying fishes observed taken at the atoll were of genus Cypselurus. Most of these were of good size, reaching a maximum of about 15 inches in length. Occasionally some half-beaks were netted.

Hook and Line: The Gilbertese fish with hook and line from canoe, from shore, or while standing in shallow water. A pole may or may not be employed. No use of set lines of any sort was observed. Usually the fisherman handles but a single line which contains but one or a very few hooks due to the great chance of loss of tackle on coral.

Fishing from a canoe takes place in the lagoon but usually over reef areas or near large coral heads. Instead of having a sinker permanently attached to the line, a stone is often loosely tied with a slip knot and the line is then lowered to the desired depth where the stone is released by a sudden jerk of the line. A great variety of fishes are taken but predominantly lutianids, labrids, carangids, serranids, balistids, and scarids.

When fishing from shore on the lagoon side of the atoll, the fishermen (frequently in this case women and children) generally wade well out into the water. Their catch usually includes small Caranx spp. and Gerres sp. and occasionally lutianids.

At low tide fishing with hook and line may be carried on in the surge channels of the reef on the seaside of the atoll. Here a pole is a great asset to the fishermen. These may be made from bamboo obtained from Ocean Island or from a local plant, Guettarda. The pole varies in length from 5 to 12 feet. The usual bait is land hermit crabs which have been removed from their gastropod shells. No sinker is used. The fishes which are most often

taken are Cirrhitus sp., Thalassoma spp., Halichoeres sp., Abudefduf spp., and Lutianus sp. These are small carnivorous fishes which occupy the special surge channel habitat.

No deep water hand line fishing was observed, but interviews with fishermen revealed that a few apparently fish to a depth as great as 100 fathoms from a canoe outside of the reef. The average Gilbertese does not have sufficient line for this or would not want to risk the loss of so much line. The fish which is most sought from the deeper water seems from native description to be the oil fish or escolar (Ruvettus pretiosus).

Torch Fishing: The equipment for this means of catching fish consists of coconut frond torches of the type described for flying fish fishing, a basket woven from coconut leaves, and either a short-handled dip net or a long knife. One man does the fishing, but customarily is followed by a second person who carries extra torches. Fishing may take place in the lagoon or on the sea side on the reef. The preferred site for torch fishing is the back ridge trough, and for this, low tide is a necessity. The water in the back ridge trough at this time is about waist deep. As the fisherman walks along he carries the torch in one hand, the knife or net in the other. The basket for the fish is slung from his shoulder and hangs at his side. Light from the torch is quite bright and fish are readily seen for the water is clear except when an unusually heavy surf is running. Usually a fish can be approached without difficulty and either scooped up with the net or cut with a rapid downward stroke of the knife. Fishes commonly caught by this method include: Cirrhitus sp., Lutianus sp., Monotaxis grandoculis, Acanthurus triostegus, Myripristis spp., Holocentrus spp., Parupeneus sp., Gymnothorax spp. belonids, and mugilids. They are ordinarily eaten immediately after the fishing operation is completed; they are roasted without cleaning in beds of hot coals.

Nets: The simplest type of net is the dip net such as employed in torch fishing. This net may also be used in a fishing operation during the day at low tide. The location is a surge channel. At Onotoa the surge channels are narrow, irregular indentations into the reef averaging about six feet in width and ten feet in depth. The water in these channels is in constant motion, and visibility from the surface or in the channel is poor because of the foam from the breakers. One man uses a coconut frond to drive fish in the channel toward a good vantage point where a second man keeps his dip net in the water. Both men stand on the reef beside the channel. This method of fishing is not a common one.

Small seines of about two fathom length and four or five feet in depth are often used. A seine may be operated by just two persons, each holding a vertical pole at each end, but usually several other persons assist by driving fish toward the net. Frequently a woven line of coconut fronds serves as an extension of the seine from one or both ends. At low tide on the reef the back ridge trough is a region which is commonly seined. One such operation was closely observed. A man, his wife, and two boys were the participants. The fish they hunted was a good-sized scarid which comes up into the shallow water on the reef in small schools. The fishermen endeavored to get between the fish and the open sea. Sometimes this involved actual running with the seine in the shallow water; at other times slow cautious movements were necessary. When the fish were cut off and tried to elude the seine, they were herded by the boys toward the net with coconut palm fronds and by splashing and throwing stones. Many large parrot fish were caught and some surgeon fish (Acanthurus triostegus) and damsel fish (Abudefduf sp.) were taken. The fishes were rendered inactive by biting the dorsal part of the skull and were strung

by cord through the eyes to one of the poles of the seine. This one fishing operation lasted several hours and covered a distance of about two miles.

In the lagoon small seines are used over shallow sandy areas and the fishes caught include Gerres sp., small Caranx sp., mullets (Mugilidae), and goatfishes (Mullidae). Here the seining is very often the work of women and children.

Small seines may be imported cotton products or may be made from local material.

Some large beach seines are owned collectively by entire villages. Each village usually has but one such seine. However, the largest village, Aiaki, is divided into two sections and each owns a seine. These are made of coconut husk fiber and may be as long as thirty fathoms. Shells are used as weights on the foot rope and pieces of a local wood (Scaevola) strung along the float line. These seines are used only in the lagoon, and their operation involves many individuals. One is designated the leader, and he directs the operation by hand signals, for noise is kept to a minimum. One end of the seine is worked out from shore in a large semicircle until it is again brought to shore at which time both ends are hauled up on the beach. The same fishes are caught with these large seines as listed above for smaller seines in the lagoon plus a few others such as lutianids. At night more larger fishes are caught, including small sharks.

One other type of net is used for a very special kind of fishing. This is a fine mesh netting (generally mosquito netting) with a slight bag and supported at four corners with poles. The net is suspended horizontally in the water between two canoes, men or women from one canoe holding two of the poles vertically in the water while those in the other canoe handle the other two poles. The area over the net is chummed with bits of fish. Small fishes

of genus Caesio are caught when they swim over the netting by a rapid pulling up of the four poles. These fishes occur in the lagoon in numbers great enough for such fishing only once every ten years or so. They tend to form small schools over coral heads in the lagoon. They are dried on coconut or pandanus mats out in the sun and stored in tight-lid containers, where they remain well-preserved for many years. The flesh is red in color when dried and considered a great delicacy.

Traps: Two types of traps are made from lashing small sticks together. The most common in use is the eel trap. This consistently has the configuration of a house (rectangular with a sloping roof), roughly three feet long and a foot and a half wide. At one end a hole of three-inch diameter can be seen. This extends, cylinder-like, toward the middle of the trap where it is narrowed by side flaps of woven coconut fiber. This trap is baited. It is set by lowering with a line from a canoe in water up to ten fathoms deep. The species of eels taken are mostly of genus Gymnothorax. A small trap door in the "roof" affords a means of removing the eels.

The second type of trap has the appearance of a small quonset hut. Size is more variable than the eel trap, but it is generally not more than three feet long. It is set by diving in water up to about three fathoms in depth. It is placed in such a manner in the coral that it can be concealed by addition of a few stones or pieces of coral. The entrance to the trap, which is similar to that of the eel trap, is kept free. This trap is not baited and is designed to capture reef fishes which tend to seek refuge under rocks or ledges of coral. These include a number of acanthurids like Ctenochaetus strigosus, scarids, holocentrids, and lutianids. A covered opening on the opposite end to the trap entrance is used to remove the fish. Such fish traps do not seem tobe utilized very frequently.

Another type of fish trap which is of considerable importance is the stone trap. These are found in the lagoon, on the reef, and in shallow passes between islands. They are constructed by piling stones into a long, low wall which encloses a large, roughly rectangular area. The wall is usually about a foot and a half high and well covered by water at high tide. As the tide lowers the top of the wall is exposed thus isolating a body of water within the trap. With further lowering of the tide the water within the trap decreases and the fish are concentrated to an extent where they may be seined or picked up by hand. The same species are taken by stone trap as were mentioned for the lagoon and reef seining operations except for mullets which escape by jumping over the wall. On the sea side the wall is occasionally broken in places when surf is heavy, and must be repaired. Here, however, red coralline algae tends to cement stone of the trap together and must greatly reduce the maintenance of the trap wall.

Tide Pool Fishing: Three means of collecting fishes from very shallow water are included here. First there is the collection of small tide pool fish by hand which is usually the task of women and children. By far the most important fish taken is the young of Epinephelus merra which are very abundant in tide pools and in shallow water lagoon areas. These are dried in the sun and eaten without cooking.

A species of moray eel, Gymnothorax picta, occurs well up on the reef flat on the sea side of the islands of the atoll. A method for capturing this species was observed. At low tide the fisherman walks over the reef, equipped with a basket with a lid and two metal rods about two feet long. One is sharpened and the other is hooked at the end. Boulders are rolled over and every likely hole in the coral is inspected with the rods, and the morays, when located, are pulled from their holes with the hooked rod.

Another method for catching eels is a simple snare device. A stick about two feet long is baited at the end with a piece of fish. A second stick has a noose which may be drawn tight.

This is placed around a hole which looks like a likely dwelling for a moray. The bait is held just outside the noose. As the moray lunges for the bait the noose is pulled tightly around his body behind the head. This is a very old fishing method but still used today. Usually it takes place on the reef flat at low tide in the surge channel area. The same method may be used in the lagoon in deeper water by diving.

Pisciculture: The milkfish, Chanos chanos, was at one time actively reared in ponds, especially one fairly large isolated body of water in the complex of tiny islands in the southern part of the atoll. The young of this species were periodically seined from outside areas and transferred to the ponds, since adults will not breed there. Such a practice has been more or less discontinued for some years.

Poisonous Fishes: Numerous interviews with groups of natives concerning the presence of fish in the atoll waters with poisonous flesh were undertaken. The only fishes which were considered poisonous at this time were the puffers and then only the internal organs, especially the gonads, were toxic. In view of the prevalence of poisonous forms throughout the whole Pacific area, it was hard to believe that there was no such problem at Onotoa. The natives were observed catching, preparing, and eating many species known to be poisonous elsewhere. Interviews did reveal, however, that a certain section of the reef near the northern part of the atoll harbored poisonous fishes for several years but for the last two years fish taken from there have not been toxic.

Fishes with poisonous spines do occur in the area, notably sting rays,

siganids, and certain scorpaenids like Pterois. The stone fish, Synancea verrucosa, was not collected but very probably occurs on Onotoa. It is reported from Tarawa.

Attacks by Sharks: Several discussions with natives were initiated in respect to this subject. Only five cases of attack by sharks on men were recalled - even by the older Gilbertese. These involved large sharks and not the common smaller forms near the reef. The natives swim around these smaller sharks without any noticeable fear. Sufficient information was not secured to identify the larger, dangerous species of sharks.

Fishing Regulations: Before the white man came to the Gilbert Islands sections of the reef flat and water areas of the lagoon were owned by men who retained exclusive rights to fish in these areas. A man who fished in another man's region risked violent punitive measures by the owner. Missionaries arrived in the Gilbert Islands around 1850 and tended to break up these holdings. When the British took over the islands as a Protectorate in 1892, the system of owning reef and lagoon areas was soon completely eliminated.

Today by native law one regulation of this sort exists. No man can fish in the vicinity of another man's stone fish trap at or near low tide.

One other interesting law exists. On the rare occasions when Caesio sp. (the special fishing method for this fish was previously described) occur in the lagoon in large numbers, no flying fish fishing is allowed. It is believed that the light from the torches will frighten Caesio away. A fine of three shillings is imposed on any man caught fishing for flying fish during this time.

No restrictions were noted concerning size limits. As far as known no species of fish were ever reserved for special individuals or occasions.

Preserving of Fish: Most of the fish is eaten fresh, the fisherman usually catching only enough for immediate family use. When more is caught, it is cut into thin pieces and dried in the sun. It may be cooked prior to drying. Usually it is not salted, and rarely is any of the catch smoked.

Abundance of Fish: No collection of catch statistics nor direct measurement of fishing effort was made, but the fishing effort on Onotoa, by atoll standards, seems high. This is due to the relatively high population and the emphasis on fishing. Nevertheless, it is doubted if any serious depletion of fish stocks has taken place, even for reef fishes. There are, however, more reef fishes to be seen by underwater observation in outlying parts of the atoll away from usual fishing activity and in other atolls with smaller native populations. Also, in the latter regions the fishes may be approached much more readily when swimming underwater.

Still, today, the Onotoan fisherman can obtain all the fish he needs in a relatively short period of time, at most two or three hours.

FISH COLLECTION ON ONOTOA

The majority of fishes which were collected during the two month's stay on Onotoa were taken with powdered cubé or derris root containing rotenone, the active poisonous ingredient. Ten successful poison stations were executed with the two hundred pounds of cubé root which was on hand.

Nearly 120 species were added to the collection by spearfishing, though many of these turned up in poison stations as well. Spearing is a highly selective means of getting fish and useful in obtaining fishes such as parrotfishes (scaridae) which are not easily poisoned. But this method has the obvious disadvantage of mutilation of specimens, and one usually fails to obtain a sufficient number of specimens of any one species in this way for ordinary

taxonomic purposes.

Considerable difficulty was experienced in procuring fishes from the Gilbertese which they had caught and which were destined for their dinner tables. This was especially true when the natives observed that most of the fish which was purchased from them did not end up as a component of the expedition's diet. Fish, they must have reasoned, should be put to but one use, food. Nevertheless, some valuable additions to the fish collection were made through purchases and trading, particularly with the children. Very material aid was obtained from the natives in recovering fishes at poison stations.

A few fishes were caught with hook and line, with use of nets, and by hand in tide pools.

Field work was dominated by making the collection of fishes, since description of the fish fauna of a new area must necessarily precede ecological studies; nevertheless, some ecological work was done. A description was made of the areas where fishes were collected. This, coupled with extensive underwater observations, made it possible to identify a type habitat for many of the species. Of course, specific habitats are difficult to delimit for marine fishes, and even when one manages with fair assurance to pinpoint a fish in a certain environment, it often pops up in an altogether different one.

Analysis of the stomach contents of fishes was made when a surplus of specimens was available. Such data were obtained for about fifty species; however, there were usually insufficient numbers of any one species examined to demonstrate total variability of food habits. Food studies which were made on fishes taken by poisoning were complicated by an unanticipated factor. Many of the fishes which are normally non-piscivorous were found to be opportunists and fed upon smaller poisoned fishes before they, in turn, succumbed

to the poison. This source of error was more or less compensated for by disregarding all recently-eaten fishes which could logically have been killed by the rotenone.

A reef transect for fishes was attempted from shore to "lithothamnion" ridge during a period of exceptional low tides and with the last of the supply of rotenone. When approximately half completed, storm conditions precluded the completion of this project.

The local Gilbertese names for fishes were recorded. It was found that smaller species frequently were not named. In fact, poisoning produced many fishes which the natives had never seen, and for which they obviously had no names. It was interesting to note how groups of similar species were often given collective names which paralleled the families of ichthyological nomenclature. Acanthurids, balistids, tetraodonts, and chaetodonts are examples; the names <u>te riba</u>, <u>te bubu</u>, <u>te buni</u>, <u>te ibaba</u> can be applied freely to nearly any fish within these respective families. The more distinctive or common members of these groups generally have more definite names, though often the above names remain as roots. <u>Acanthurus achilles</u>, for example, is called <u>te ribataukarawa</u>. There was not always complete agreement among the Gilbertese for their names of fishes, especially for the rare species.

The fish collection from Onotoa comprises about 325 species. These still bear field identifications to a large extent, and thus no taxonomic report can be presented at this time. The following is a breakdown of the collection on a family basis and will serve to give some idea of its extent and the predominance of certain families over others:

Family	Number of Species
Acanthuridae	15
Antennaridae	2
Apogonidae	10

Atherinidae	1
Aulostomidae	1
Balistidae	6
Belonidae	2
Blenniidae	16
Bothidae	1
Brotulidae	2
Canthigasteridae	3
Caracanthidae	2
Carangidae	5
Carapidae	2
Chaetodontidae	17
Chanidae	1
Cirrhitidae	6
Echelidae	2
Echidnidae	26
Eleotridae	6
Exocoetidae	2
Fistularidae	1
Gerridae	1
Gobiidae	10
Hemiramphidae	2
Holocentridae	16
Istiophoridae	1
Labridae	34
Lutianidae	17
Monocanthidae	4
Moringuidae	3

Mugilidae	3
Mullidae	6
Ophichthyidae	1
Ostraciidae	1
Parapercidae	1
Permpheridae	1
Platycephalidae	1
Pleuronectidae	1
Pomacentridae	29
Priacanthidae	1
Pseudochromidae	4
Scaridae	22
Scorpaenidae	8
Seriolidae	1
Serranidae	13
Siganidae	2
Sparidae	1
Sphyraenidae	1
Syngnathidae	2
Synodontidae	2
Tetraodontidae	3
Thunnidae	3
Zanclidae	1

At least twenty-five additional species were observed underwater but were not taken. Many of these were provisionally identified.

Only three sharks were captured. Some rays were seen but were not taken.

An opportunity provided itself to test the efficacy of copper acetate as a shark repellent. The following is taken directly from my field notes: "Two sharks (Triaenodon obesus) were observed by Dr. Banner and myself slowly circling an area where it is believed a speared (and hence bleeding) fish was seeking refuge in a hole in the coral. The water was about eight feet deep and fairly clear. The sharks were estimated at $4\frac{1}{2}$ and $5\frac{1}{2}$ feet in length. The smaller shark was seen on two occasions to stick his head down the hole, thus exposing his body vertically in the water. From time to time the sharks would leave the area, either singly or together, but always they returned. They were never observed to swim rapidly. A small tin of copper acetate crystals was dispensed by Dr. Banner in a circle of about twenty-five feet in diameter around the area. At this time the sharks were absent. The smaller shark was then observed to approach the area but not enter it. The larger shark, on reaching the cloudy area where the acetate had precipited, turned sharply around and swam very swiftly away. Within at least the next ten minutes neither shark was seen at all."

Over two hundred color photographs of fishes were taken with 35 mm Kodacolor film. Most of these were satisfactory.

ATOLL RESEARCH BULLETIN

No. 14

Description of Kayangel Atoll, Palau Islands

by J. L. Gressitt

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DESCRIPTION OF KAYANGEL ATOLL, PALAU ISLANDS

By J. L. Gressitt
Pacific Science Board

Kayangel Atoll is the northernmost land area of the Palau Archipelago in the western Caroline Islands, except for Ngaruangl, a sand bank on an incipient atoll to its north. There are no other atolls within 150 miles. Kayangel is separated from Babelthuap, the largest island of the Palaus and a volcanic island, by about twenty miles of water. Between, there are only two small islands, Ngaregur and Ngarekelau, just north of Babelthuap, and the large "V"-shaped Kossol Reef pointing towards Kayangel, in the middle of the intervening space. Other reefs extend somewhat north of Babelthuap to the west, particularly, and also to the east. From the hill above Olei at the north end of Babelthuap, Kayangel may be seen as if it consisted of a small islet at the left and a long one to the right (east).

Kayangel is a small atoll, with a north-south diameter of less than three and one-half miles and an east-west diameter of only two miles. The atoll consists of an almost complete circle of reef, with four islets. The latter are all on the east side, occupying a little less than the eastern half of the perimeter. The islets decrease markedly, and somewhat geometrically, in size, proceeding from north to south. The entrance to the lagoon is not very distinct, and is shallow. It is located on the west side a little north of the center, and west of the pier at the middle of the main island. It consists of a sand-bottomed break in the reef a number of yards wide and extending obliquely inward in a northeast direction. It is only one to two fathoms deep at low tide and is dotted with coral heeds of varying size, so that passage of craft larger than canoes must be undertaken at very slow speed, and is very dangerous in rough weather. At high tide in good weather a craft of less than one fathom draft can pass over the reef at the south end, one hundred yards west of Gorak Islet.

The lagoon is largely of sand bottom and varies from very shallow to a few fathoms deep. Most of the southeastern one-third of the lagoon is less than two fathoms deep and has large scattered coral heads except in the shallower parts. In some shallow areas east of the center or near the center of the main island stag-horn coral grows on the bottom. Quite a bit of it has been broken by canoes or fishing operations. In the central and northern parts of the lagoon the water is deeper with the coral heads less visible. In the southwestern part the coral heads are quite large and widely separated, and the water a few fathoms deep. In the western part the coral heads are closer and the water shallower approaching the inlet.

The reef forming the atoll is, in general not very wide on the west side, and the water becomes deep rather soon, particularly near the south end. At several points there are large blocks of coral rock which have been washed up onto the reef, and two of these on the southwestern part are even visible at moderately high tide. At lowest tide the reef is visible at a number of points in the different parts. On the east side, seaward of the islets, there is for the most part a fairly flat platform exposed at low tide. It consists of more or less solid coral limestone, marked in part with tidal pools of a shallow nature and with old coral structures generally evident. At some points, particularly near the ends of the islets, masses of coral rocks or gravel have been washed up. The sea bottom slopes off at an initial grade of 10-25 degrees.

The

The intervals between the islets are rough and rocky, with tilted coral slabs in part, on the seaward side, and sandy on the lagoon side. At lowest tide it is possible to walk between the two northern and the two southern islets largely on exposed sand, with only short distances to wade in shallow water. The route between the two northern islets is over very fine white sand in a large broad arc curving into the lagoon, whereas between the two southern islets it is almost direct but the sand is mixed with coral gravel in part. The water is deeper on the lagoon side between the middle islets, and the distance is greater and there is some coral growth. Near the south end of the lagoon side of the second island (Ngariungs) are some eroded mushroom-shaped blocks of coral rock exposed at low tide, some of which have fallen over.

The east or seaward shores of the islets consist for the most part of fairly narrow sloping beaches of rough coral gravel or accumulations of coral rocks with almost no sand. On the main island, however, there is a higher proportion of sand on the east coast, even to pure sand or only partially mixed with broken coral gravel. The west or lagoon shores of the islets are almost entirely of sand beaches, though the sand is rather coarse and mixed with coral fragments in part. Near the north end of the lagoon side of the second island (Ngariungs) there is an area of solid coral rock, or beach sandstone, mostly of irregular, flat or sloping surfaces, with some up-tilted slabs or boulders. The ends of the islets are more rocky and have narrower beaches. The north ends are largely gravelly. The south ends of the second and fourth islets are largely rocky, that of the main islet is sandy with some rocks or gravel, and the south end of the third islet (Ngarapalas) is largely sandy. There is at least some sand at the north end of the north island.

Kayangel Atoll apparently has a rather wet climate, with an estimated annual rainfall of perhaps 150 inches. The four islets are almost entirely covered with vegetation. This includes about 13,000 coconut palms in the less than one square mile of land area, but also quite a bit of apparently natural vegetation. The human population in 1951 was 124, the village being on the main island. Coconut palms grow on all four islets, but taro, breadfruit and other crops only on the main island, except for a little near the north end of Ngariungs Islet. The altitude above high tide water level is largely from three or six feet except where it is raised a few feet higher by the nests of megapode birds or by artificial coral-slab platforms of houses or graves.

The main island, or Ngajangel, the northernmost, is the largest. It is about one and one-third miles long and about one-quarter to two-fifths of a mile in width, being narrower towards the south end. The pier is located near the middle of the lagoon side. The village extends in a double row of widely spaced houses along a pair of parallel avenues near the lagoon shore for about one-third the length of the island from a little north of the pier to the beginning of the south quarter, where the school and the old cemetery are located. Near the pier and the cemetery there are some very large Calophyllum inophyllum trees with platforms of coral slabs built up around their trunks. Along the beach in the village area are some canoe sheds, including some large ones near the pier, and a number of small copra drying sheds. Along the beach grow Hibiscus tiliaceus, Barringtonia, Messerschmidia, Scaevola, Hernandia, Thespesia and other common strand plants. Behind these tower coconut palms in regular rows, spaced about five yards apart. The palms were planted by the Germans and are about 60 years old and 50-60 feet tall. The trunk of most of them has an orange colored alga growing on the surface. The palms are apparently in good

condition

condition, with fair yields. They grow almost the entire length of the west side of the island, except near the north end. The east half of the island has some younger coconut groves, but they are mostly limited in area and do not reach the east coast. The remaining area is largely of mixed second growth, except for the cultivated areas, and includes some very large trees (one with almost creamy white bark) and some rather dense growth. The north end appears more natural and less disturbed, and has quite a variety of plants. Pandanus tectorius grows along the entire east coast, as well as elsewhere, in places forming rather dense tangles.

In the northcentral, broadest part of the main island are the taro beds, consisting almost entirely of the large false taro (Cyrtosperma chamissonis, "b'rock") growing in large submerged areas. Some small areas of ordinary taro (Colocasia esculenta, "ku-kao") are found nearer the village. Some cassava (tapioca) fields are scattered in patches in yards in the village, and also in clearings in the eastern half of the island. Breadfruit trees and banana and papaya plants grow largely in the neighborhood of the houses, but there are also some in scattered clearings, one even near the southeastern shore of the island, which is largely grown up with very tall weeds. There are a number of lime trees growing in the village, producing a surplus of fruit. Betel palms are rather scarce. A few dwarf coconut palms grow in yards in the southern part of the village.

Just north of the village is the principal water supply for the community. It consists of a pool of slightly brackish water about three yards square, walled by large squared blocks of coral rock. The water is frequently at about the same level as high tide. Toads (Bufo marinus) introduced since the war to control monitor lizards (Varanus indicus), are numerous in the pool and contaminate it by dying in the water or in crevices between the rocks. (The monitor lizards are controlled by feeding upon the toads and being killed by their poison glands.) The introduction was an unfortunate one, since not only do the toads pollute the scarce water supply, but the monitor lizards are predators upon the coconut rhinoceros beetle, recently introduced into Kayangel. The introduction was made because the monitor lizards prey upon chickens, but the coconut palm is far more important to the Palauans than are their chickens. In addition to the above pool there are some smaller, less elaborate pits dug for water, which generally contain a few inches of water.

The second island, Ngariungs, is both narrower and shorter than Ngayangel. It likewise tapers somewhat from north to south. Just over one hundred yards from the north end of the islet is a shallow inlet from the east coast which widens in the middle of the island and reaches to within 25 yards of the western shore. Its floor is partly of coral rock and partly of mud or sand, and it contains a small amount of mangrove, probably all that is found in the atoll. There is a small island (at high tide) near the western edge of the inlet. At low tide the deeper part forms a small brackish lake.

The wide northern end of Ngariungs is largely covered with rather heavy jungle, including some large trees of a few feet in diameter with somewhat buttressed trunks.

Among these were many vines, including Epipremnum pinnatum and Mucuna sp., also birds nest ferns, Asplenium nidus. Not far from the northeast corner there

are

are some small clearings in the jungle where some false taro, tapioca and squash vines still grow, though poorly tended. At the extreme north end of the islet there is a small tin-roofed shelter and an oil drum which collects the rain water which runs down the trunk of a Pandanus plant. In the shady jungle nests of megapode birds are common, some of them measuring 25 feet in diameter and five feet in height. They consist of sand and bits of worn coral from the jungle floor, after the vegetable matter which incubated the eggs has rotted away. One or two old worn down nests were also seen on the main island. The young birds emerged from one nest on Ngariungs between visits two days apart, in September. The birds were frequently heard in the dense jungle. Other land birds seen were kingfishers (Halcyon chloris teraokai) and the morning bird (Colluricincla tenebrosa). Several monitor lizards were seen.

The part of Ngariungs south of the inlet has fewer tall trees, but is rather densely covered with second growth forest. Coconut palms were limited in number to only about 330 grown palms, of which quite a number have been killed and consumed by the coconut beetle, which reached this islet first, of Kayangel, about 1946. The largest were just west of the inlet, and are all lost. The jungle has grown up around most of the remaining palms, which are seriously affected by the beetle. This islet was inhabited by American troops just before and after the close of the war.

The third islet, Ngarapalas, is again much smaller than Ngariungs, and is separated from it by much more than its own length. It is broad at the north end, where it is largely covered with dense scrub jungle of rather short trees, except on the west side which is partly bare except for rows of coconut palms up to ten years in age. This western part consists of coral gravel. There are some taller coconut palms near the center of the islet and around the cove on the east side. The eastern part of the tapering southern portion of the islet has some low scrub. The northern part of the east shore is of rough coral limestone with loose coral rocks washed up. The southern part of the east coast is sandy, and here high on the beach a large sea-turtle nest was found containing at least 100 eggs. Off of this beach is a large platform of rough coral rock, somewhat uneven in nature, which is largely exposed at low tide and which connects with the last islet.

The southernmost islet, Gorak, is much smaller than Ngarapalas, and close to it. Most of its northeastern half is flat and almost barren, with just a few shrubs and young coconut palms. Some terns and other sea birds lay their eggs among the coral pebbles and drift wood on this open area. Triumfetta procumbens and some low-lying prickly herbaceous vines grow on this portion. Scaevola and a few other plants are also present. The remainder of the islet, roughly rounded, bears about 55 coconut palms mostly about 40 feet in height, besides some younger ones, some of which extend north a short distance along the edge of the beach on the west side. Just a few other shrubs and small trees flank the coconut palms, or are mixed with them. The east and south shores of the islet are covered with piled up coral rocks. Some floating logs from elsewhere have been washed ashore by storms, even to the center of the islet, which is less than 100 yards across. From Ngariungs, Ngarapalas appears to be several times as long as Gorak because it is nearer and more fully covered with tall vegetation. Ngarapalas islet is owned by the chief of Kayangel, and Gorak islet by the second chief.

The

The northeastern end of Gorak Islet, the southwestern end of Ngarapalas islet, and to a lesser extent the northwestern corner and south end of Ngariungs appear to have been added to since earlier maps were made, as those portions consist largely of coral rocks, rubble and sand. In the case of the former two the material is raised approximately to the general level of the islands. New vegetation is taking root on those situations and to some extent on the point extending towards the sandflats on the northwestern corner of Ngariungs, where the sand is also raised fairly high. The plants involved are mostly Barringtonia, Cocos and some creeping vines including Triumfetta. The common moth Utetheisa was extremely abundant on Gorak islet, presumably breeding on Messerschmidia.

The soils of Kayangel consist largely of coarse loamy sand, sometimes mixed with coral gravel, but in some parts, such as much of central Ngajangel it consists largely of gravel, with or without a thin layer of sand or loamy sand on the surface.

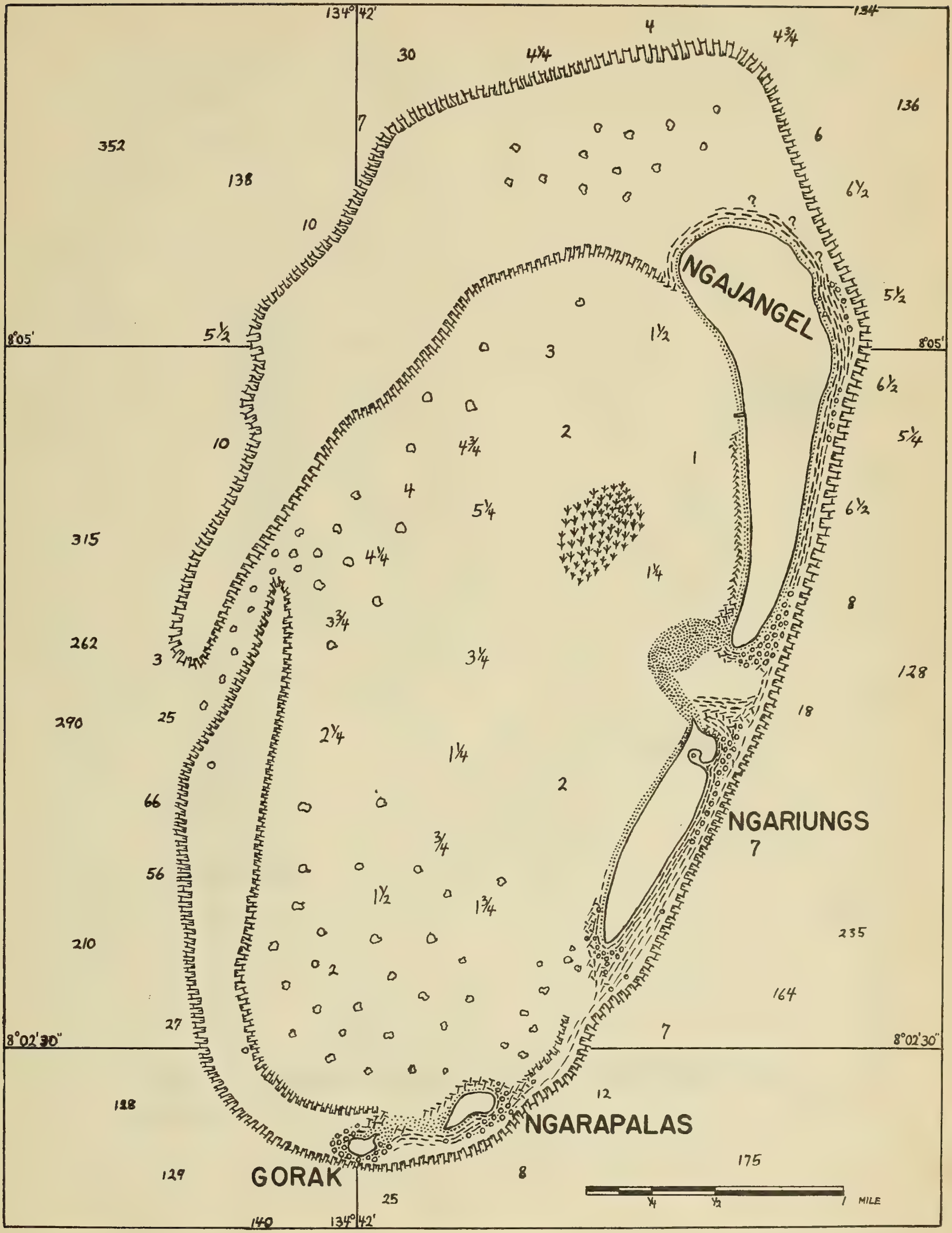
A small rat (Rattus exulans?) is common around stumps or in the small grassy areas between coconut palms on the main island. Examination of four stomachs showed that they fed almost entirely on copra, probably from the drying sheds along the lagoon beach.

The above notes are based on visits to Kayangel Atoll during July 24-25, September 13-17 and November 24-25, 1951. The northeastern corner of the main island was not seen, and its northern tip was seen only at high tide. On the two maps the outer reef outline and outline of main island were taken from A.M.S. W752 (1942, 1943) and the soundings from 64th Eng. Top. Bn. USAFCPBC No. 1023 (1944) based on H. O. Chart 6074.

LEGEND FOR MAPS

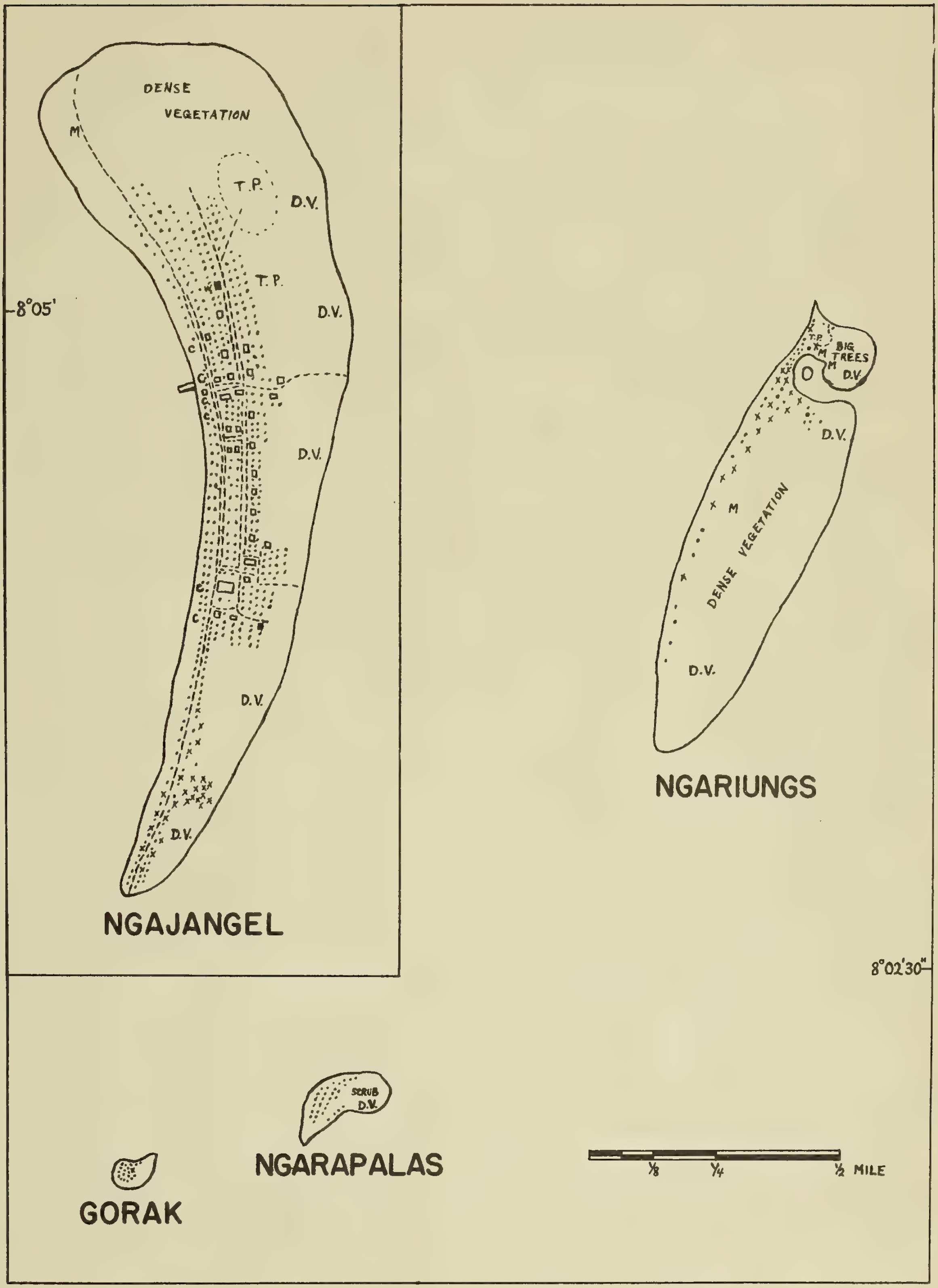
	Coral heads
	Edge of coral reef
	Staghorn coral
	Solid reef limestone
1 3/4	Soundings in fathoms
	Sand exposed at low tide
	Coral gravel
	Loose coral rocks
	Beach sandstone
D. V.	Dense vegetation (semi-natural)
T. P.	Taro pits
M.	Megapode nests
: : :	Coconut palms
x x	Coconut palms killed by coconut rhinoceros beetle
w ■	Well
	Houses, a-bais or school
----	Paths
===	Main avenues

KAYANGEL ATOLL



MAP NO. 1

ISLETS OF KAYANGEL ATOLL



MAP NO. 2